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ADVANCED WASTE TREATMENT AND WATER REUSE SYMPOSIUM HELD AT ADOLPHUS HOTEL, DALLAS, TEXAS ON JANUARY 12-14, 1971. SESSION 5

Federal Water Quality Administration
Cincinnati, Ohio

1971

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ADVANCE WASTE TREATMENT AND WATER REUSE SYMPOSIUM

Adolphus Hotel

Dallas, Texas

January 12-14, 1971

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Texas Water Quality Board

Session #5
Thursday, January 14

Moderator: Hugh C. Yantis, Jr.
Executive Director
Texas Water Quality Board

9:00 A.M. Solids Removal Processes
Dr. S. A. Hannah

9:30 A.M. The Porteous Process
James Phillips

10:00 A.M. Demineralization
Jesse M. Cohen

10:45 A.M. Bacterial & Viral Control & Water Reuse
Dr. Harold W. Wolf

11:30 A.M. The Concepts Of Wastewater Reclamation
Gene Suhr

12:00 N Summary - Closing Remarks
Hugh Yantis, Jr.
F. M. Middleton
R. A. Vanderhoof

1:30-4:30 PM Inspection Trips
City of Dallas Water Reclamation Plant
City of Richardson Wastewater Treatment Plant

III

SOLIDS REMOVAL PROCESSES

Sidney A. Hannah

ADVANCED WASTE TREATMENT AND WATER REUSE SYMPOSIUM

South Central Region, FWQA

Dallas, Texas

January 12 - 14, 1971

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SOLIDS REMOVAL PROCESSES

Sidney A. Hannah

If one were to rank wastewater treatment operations in order of overall importance, separation of solids from liquids would probably assume major importance. This operation may be required to remove objectionable components from a waste, to render the waste more amenable to subsequent treatment or disposal, or to support another treatment operation.

SEDIMENTATION

Sedimentation tanks are employed for various applications which have one common objective - the removal of solid matter from a flowing liquid. The solid matter may have been present in direct suspension, such as in municipal sewage, or may alternatively be a precipitate resulting from prior chemical treatment, such as lime precipitation or alum or iron coagulation.

Horizontal Flow Design

The principal basis of the earliest designs of horizontal-flow sedimentation tank was the "retention time". The objective was to move water so slowly through the tank that there would be ample time for settlement. The nominal detention period allowed was usually more than four hours. However, each drop of water did not take the same time to travel from inlet to outlet, since some degree of "short-circuiting" was bound to occur. In fact, a typical pattern of flow under ideal conditions in an elementary design of a horizontal-flow tank is represented by Fig. 1. Diagram (a), solid line, represents the most favored flow-path, while the dotted lines indicate typical eddies which are induced in the remainder of the tank volume. Diagrams (b) and (c) represent the flows which result, respectively, to entering water being warmer or colder than the water in the tank.

The basic design which has been most widely used for sewage treatment is a tank circular in plan. The inflow is introduced at the center of the tank and the outflow is collected at a peripheral launder. As the general direction of flow is mainly a radial spread from the center, it is reasonable to regard this design as in the horizontal-flow category.

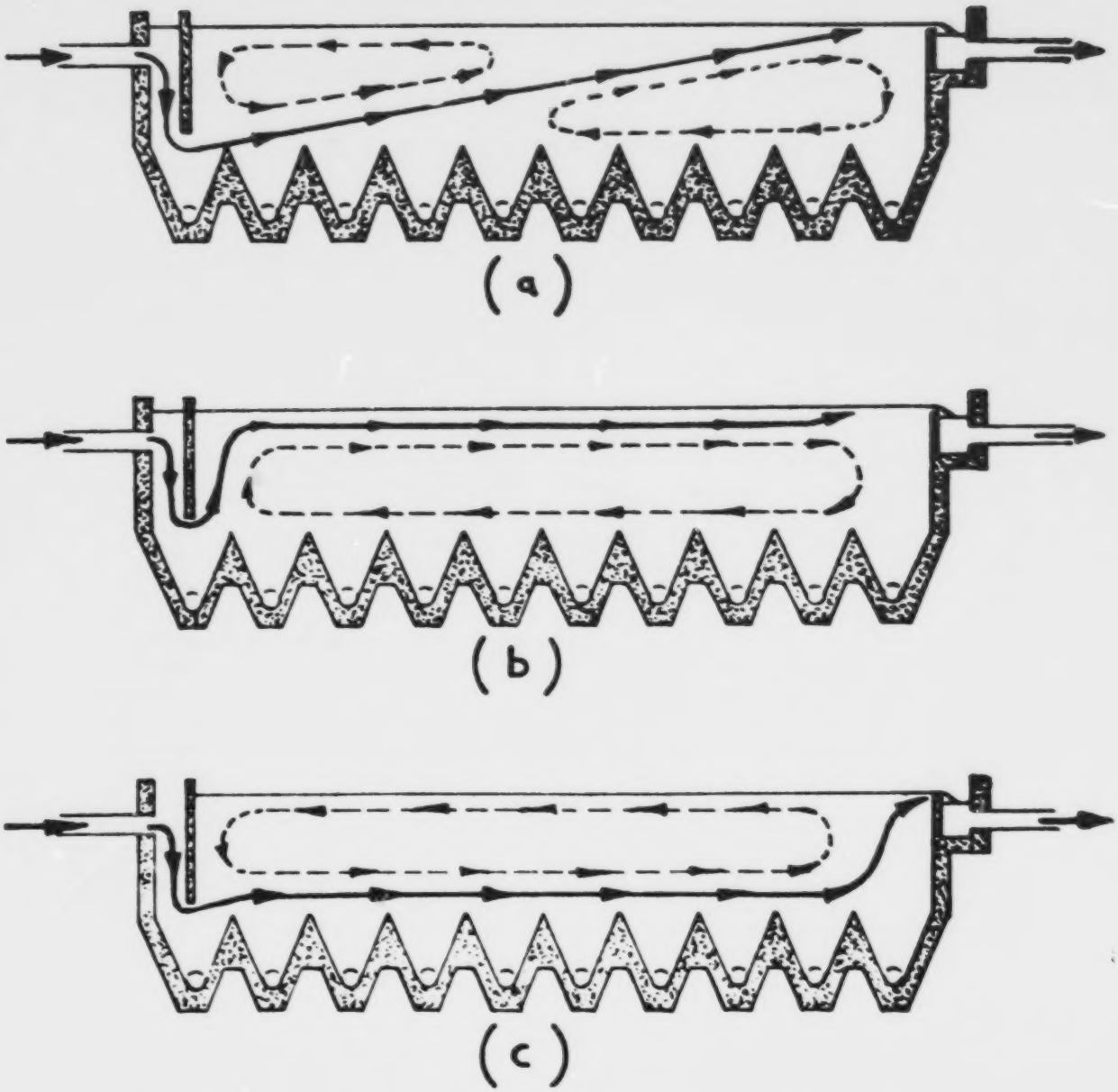


Figure 1—Sedimentation tank of horizontal-flow type under different conditions of relative temperature.

Vertical-Upflow Design

The improved performance obtained in upflow tanks has led to a variety of new designs, incorporating variants of the upflow principle. These new designs are designated by various proprietary names - Accelator, Clarifow, Flocsettler, Reactor-Clarifier, etc. One of the earliest of the upflow tanks was the Spaulding Precipitator, shown in Fig. 2. In this design, the flow is introduced into the center of the tank and flows upward through a blanket of previously formed solids.

The principal advantages of the upflow versus the horizontal tanks are (1) improved flow control, and (2) sludge blanket effect. Salt-injection tests performed on a variety of tank designs clearly show the superior efficiency of the upflow principle in the matter of flow control. The radial-flow still largely used in sewage treatment is distinctly inferior, being subject to short-circuiting.

Tube and Lamella Settlers

In an ideal settling basin, as defined by Camp, the paths of all discrete particles will be straight lines, and all particles with the same settling velocity will move in parallel paths. The settling pattern shown in Fig. 3 would be the same for all longitudinal sections. It is apparent from this that as the interval (h) is reduced, the size of the basin required to remove a given percentage of the incoming settleable material decreases. Many devices have been proposed since this principle was first proposed by Hazen in 1904 and further developed by Camp in 1946. None of the proposed devices were accepted commercially until the recent introduction of the device called the tube settler. These consist essentially of closely packed small diameter tubes, 1-4 inches in diameter and 2-4 feet in length, inclined at some angle to provide for removal of sludge as the water flows upward through the tubes. Detention times are in the order of 6 minutes and less. The tubes provide as much as 24 hours of sludge storage, depending of course, on the amount of suspended solids, and sludge is readily removed by gravity drainage. A schematic diagram of the tube settler integrated into a complete clarification device which consists of coagulation-flocculation, a tube settler unit and a mixed media filter is shown in Fig. 4. More recently, a device consisting of parallel plates rather than tubes has become available. The device is called a lamella. Flow is co-current in contrast to the countercurrent flow of the tube settlers. The plate arrangement in a tank is shown in Fig. 5.

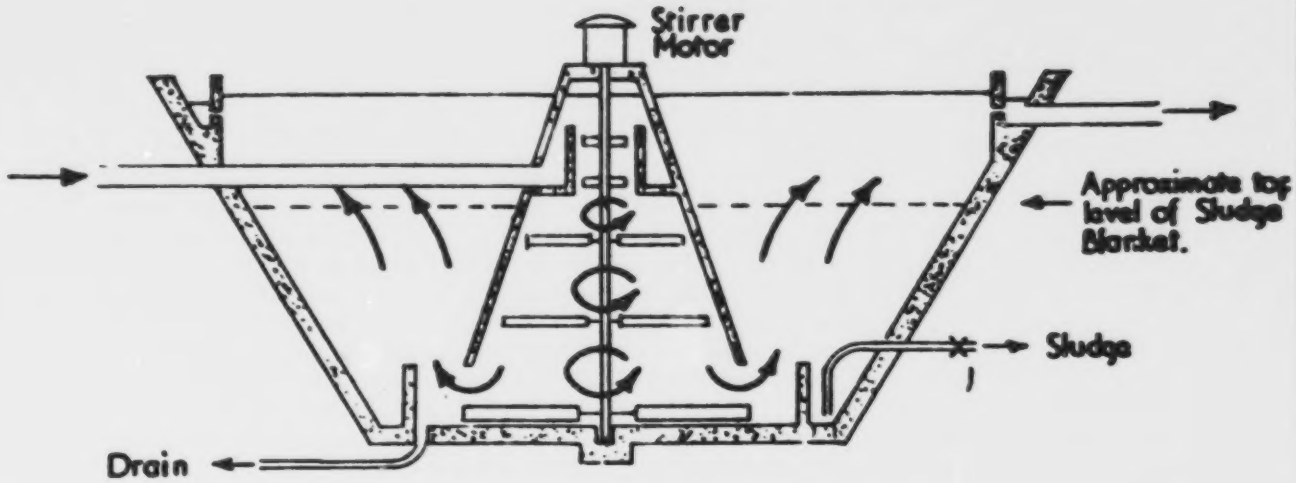


FIG. 2 — *Spaulding Precipitator*

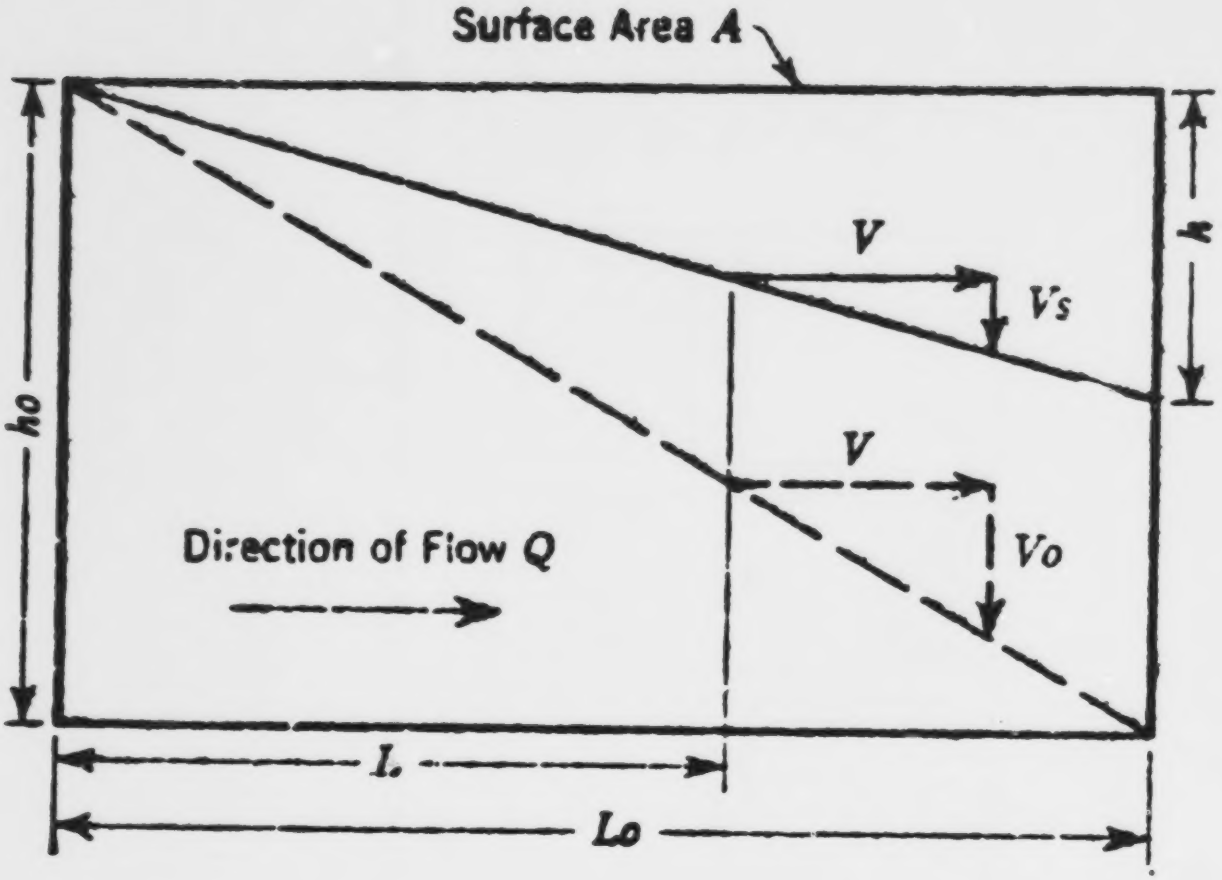


FIG. 3 **Idealized Settling Paths of Discrete Particles in a Horizontal Flow Tank**

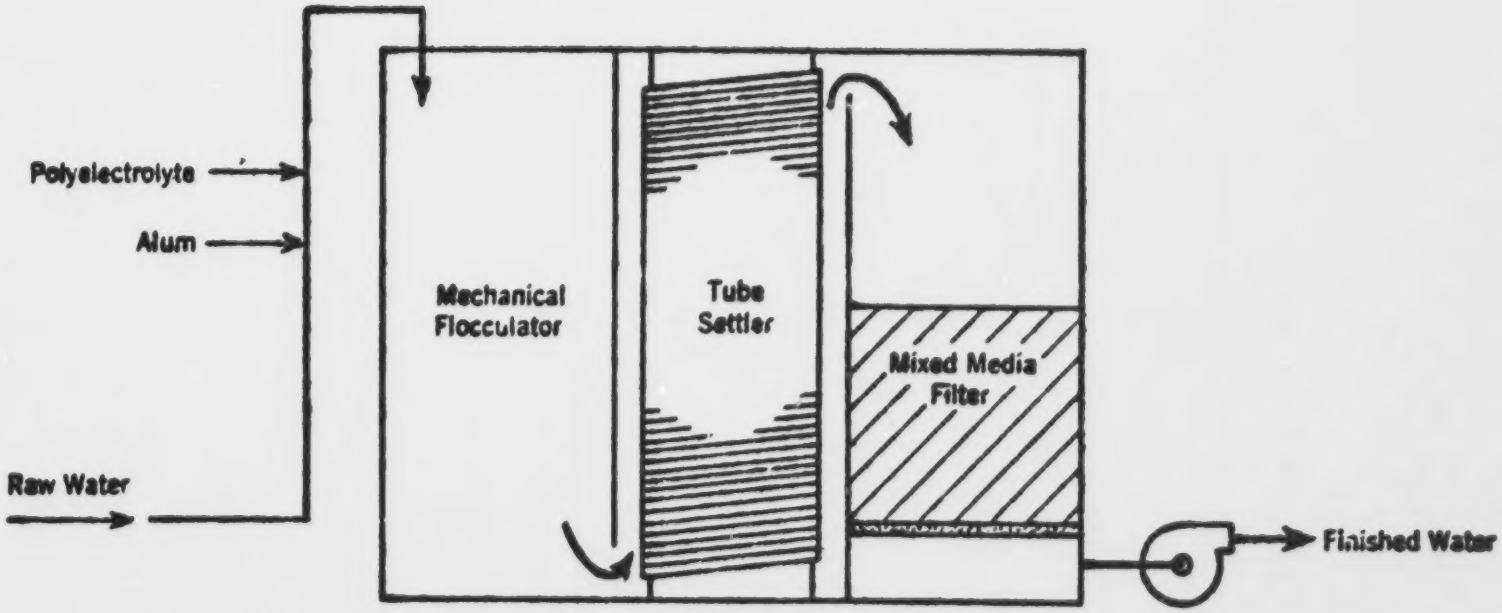
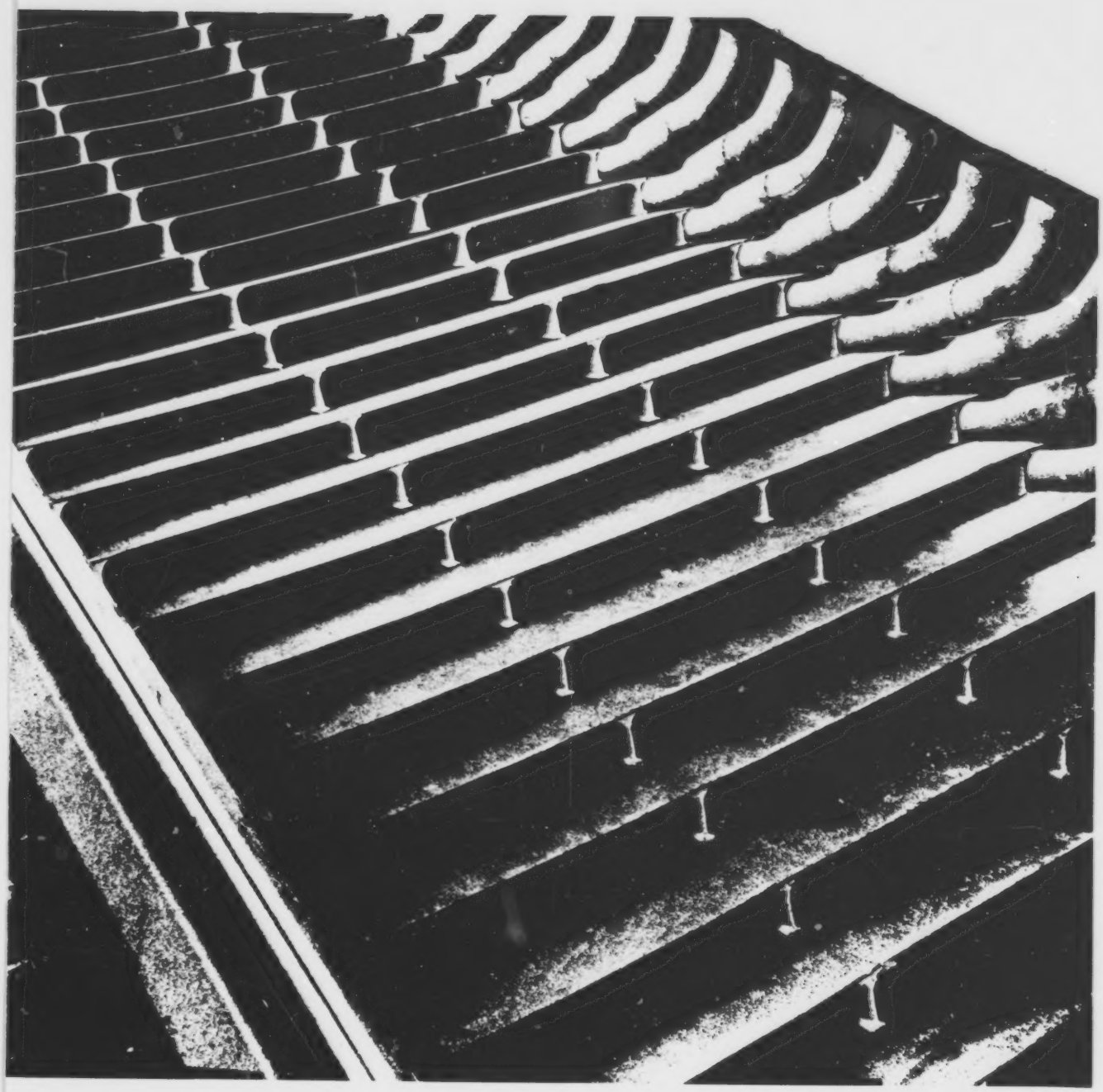


Fig. 4. Schematic Diagram of Apparatus Used in Field Tests of Tube Settler

Figure 5 Lamella Separator



DISSOLVED AIR FLOTATION

The use of dissolved air to float suspended solids was first used in industrial operations. In recent years, the process has been adapted to domestic wastewater and particularly to sludge thickening. The process achieves the separation of suspended particles by attachment of gas bubbles to the suspended particles, thereby reducing the effective specific gravity of the particles to less than that of the water.

A. A flotation system using the pressurization and de-pressurization sequence consists of the following elements (Fig. 6).

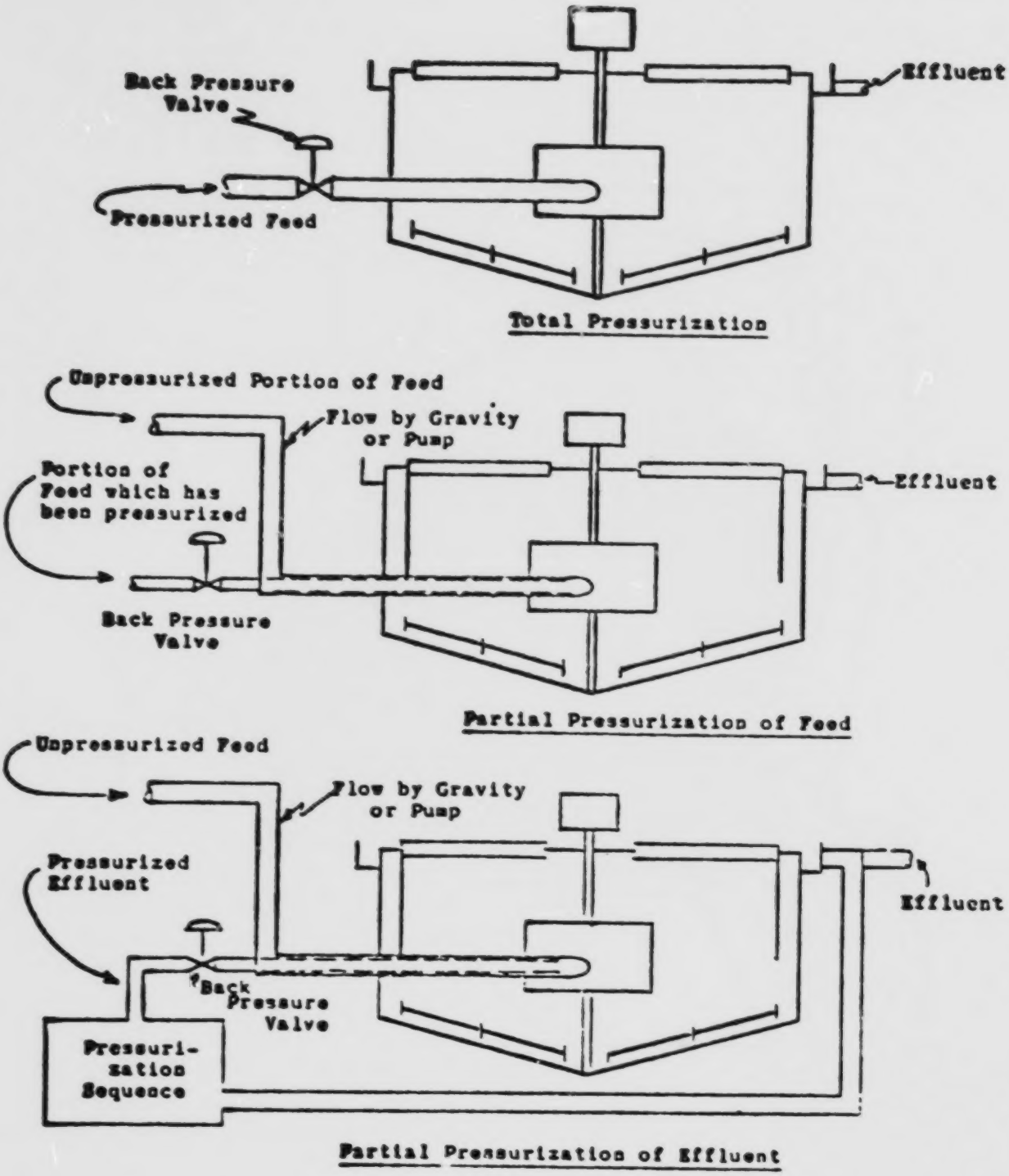
1. Pressurizing pump
2. Air injection facilities
3. Retention tank or contact vessel
4. Back-pressure regulating device
5. Flotation device
6. Facility for addition of chemicals if needed

B. Advantages and Disadvantages

1. Much reduced retention time - 10-20 minutes
2. Greater solids concentration in float than in settled sludge
3. Greater efficiency of solids recovery
4. Offers mechanical control over the process
5. Increased cost of operation for pumping, etc.
6. Need to remove top and bottom solids

SCREENING DEVICES

Microscreening is a form of simple filtration by straining (Fig. 7). These mechanical filters consist of a rotary drum which revolves on a horizontal axis. The peripheral surface of the drum is covered with a stainless steel fabric. The effectiveness of the woven mesh screen for retaining fine particles is dependent on the size of the openings in the screen and on the pattern of the weave. Influent enters the open end of the drum and is filtered through the fabric with the intercepted solids being retained on the inside surface of the fabric. As the drum rotates, the solids are transported and continuously removed at the top of the drum by pumping strained effluent, under pressure, through a series of spray nozzles which extend the length of the drum. The solids and wash water are collected in a central trough within the drum and discharged through a hollow axle. The microstraining device is available in several unit sizes ranging from 5' in diameter and 1' width with a capacity of 0.05 to 0.5 mgd to 10' diameter and 10' wide with a capacity of 3-10 mgd.



Methods employed for partial and total pressurizations.

Figure 6

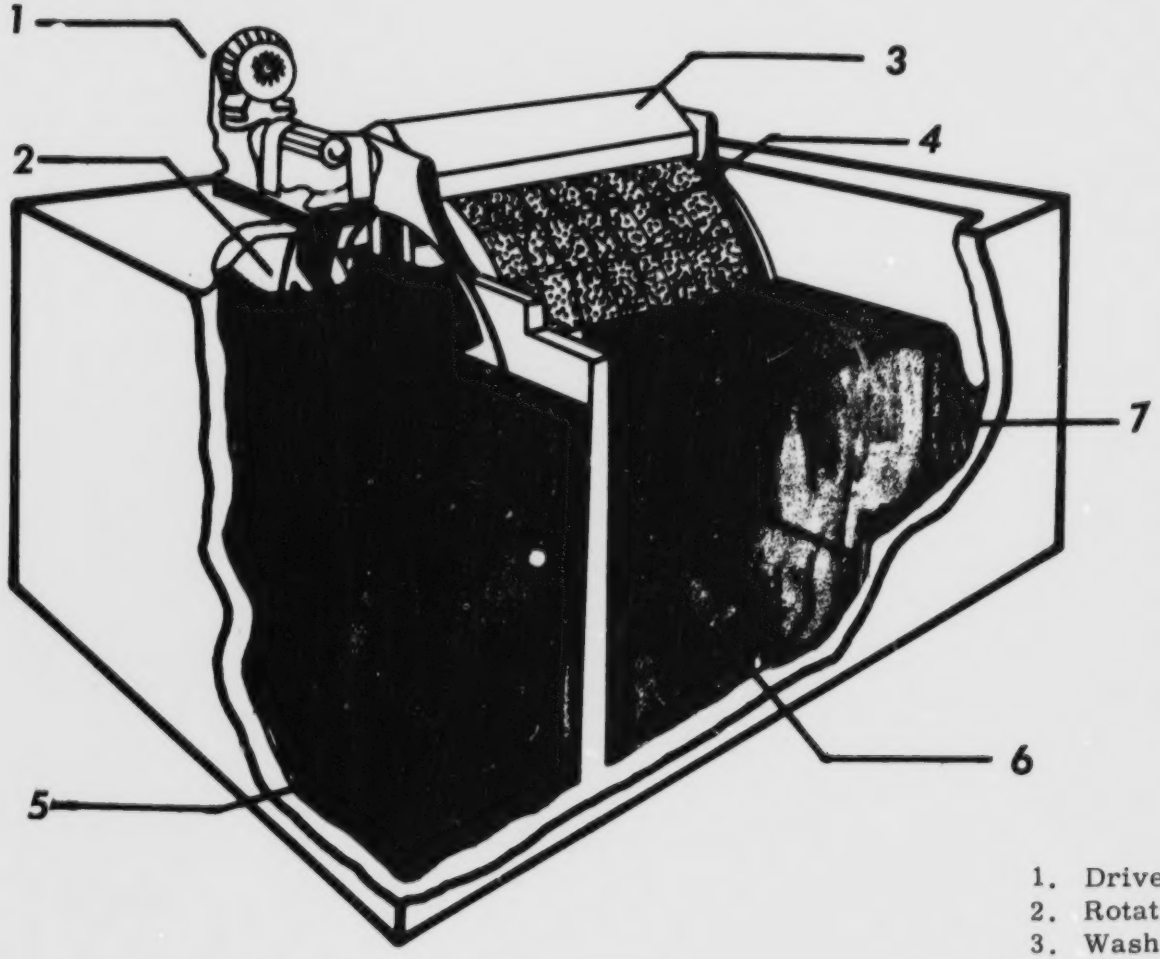


Fig. 1 Typical Microstrainer Unit

1. Drive Unit
2. Rotating Drum
3. Wash-water Jets
4. Micro-fabric
5. Influent Chamber
6. Effluent Chamber
7. Effluent Weir

Not Shown

Wastewater Hopper
Ultra-violet Lamp
Wash-water Pump

FIGURE 7

Microscreening devices have found their greatest application to treatment of river waters, and information on their performance on wastewaters is quite scarce. The effect of aperture size on removal efficiencies and flow rate is shown below.

Fabric	Removal Efficiency		Flow
	Solids	BOD	gals/hr/ft^2
Mark 0 (23 microns)	70-80%	60-70%	400
Mark 1 (35 microns)	50-60%	40-50%	600

The advantages of microstraining are the low initial capital cost and ease of operation. The disadvantages are the incomplete solids removal and the inability to handle solids fluctuations.

Capital and Operating Costs

The capital and operating costs associated with microstraining have been prepared by Smith and are shown in Fig. 8. For a 10 mgd plant, total cost for microstraining is calculated to cost about 1.5¢/1000 gallon.

In-Depth Filtration

In-depth filtration is the passage of a fluid through a bed of granular media designed to permit the captured particles to be retained within the filter. The degree of penetration and solids removal efficiency can be altered by changing the size and character of the particulates to be removed as well as the size and composition of the filter media itself.

A basic prerequisite for the operation of rapid sand filters is that good coagulation and flocculation must be obtained. Barring adequate pretreatment of the wastewater, filtration efficiency is decreased as evidenced by "breakthrough" of floc. With good pretreatment by coagulation, higher filtration rates are attainable while still maintaining clarity of the effluent.

It is beyond the scope of this talk to discuss the subject of coagulation and flocculation. A variety of coagulants and flocculants are available including various salts of aluminum and iron, lime and organic polymeric flocculants. The former inorganic salts, in the proper dosages can also provide for precipitation of phosphate in addition to clarification.

MICROSTRAINING OF SECONDARY EFFLUENT

Capital Cost, Operating & Maintenance Cost, Debt Service
vs.
Design Capacity

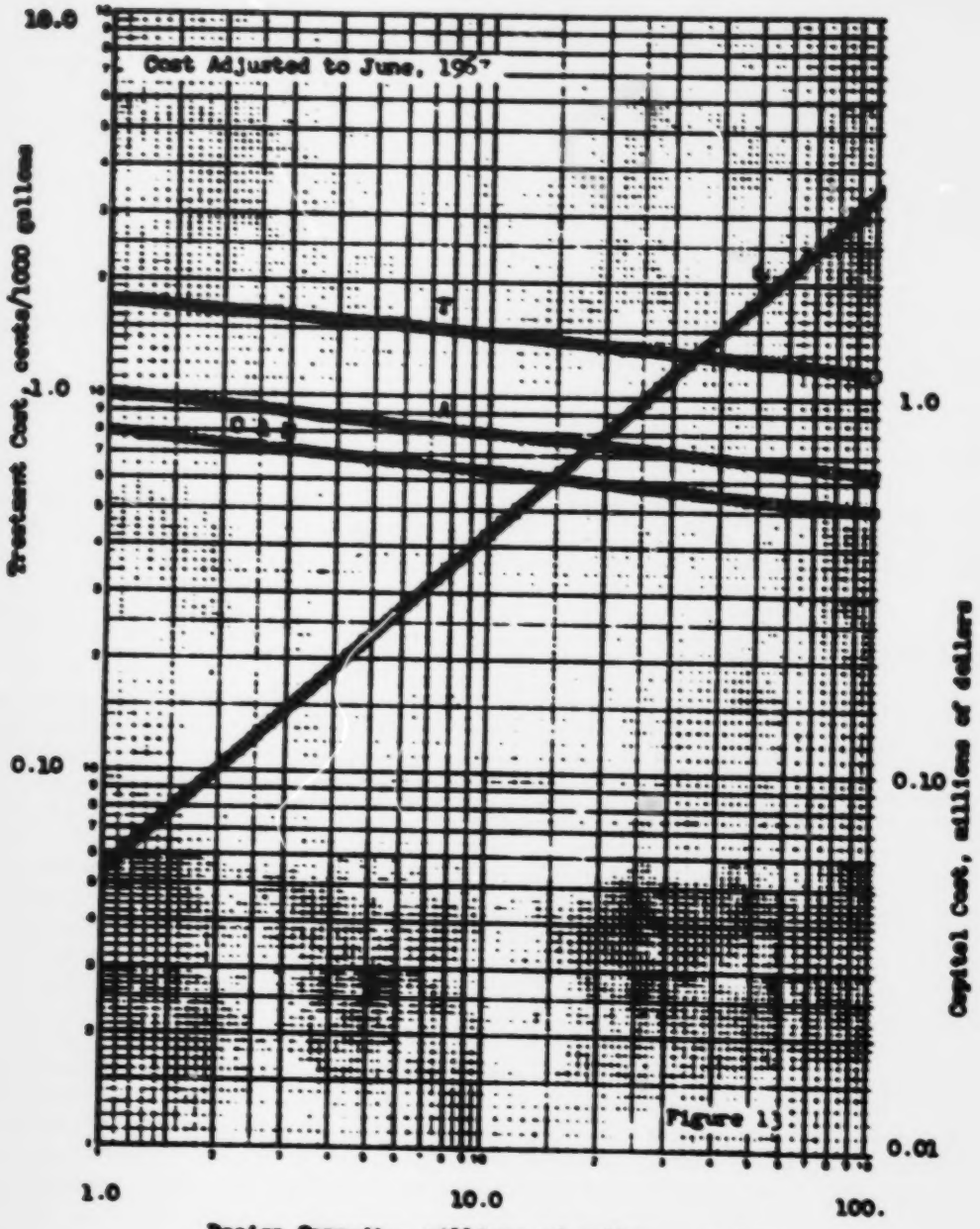


Figure 13

C = Capital Cost, millions of dollars
A = Debt Service, cents per 1000 gallons(@ 1/2% - 25 yr.)
O & M = Operating and Maintenance Cost, cents per 1000 gallons
T = Total Treatment Cost, cents per 1000 gallons

FIG. 8

In the past 70 or 80 years there has been a gradual improvement in the basic process of media filtration. Some of the earlier work centered on increasing the filtration rates of slow sand filters to the modern rapid sand filter rates. Various cleaning methods were also developed including backwashing and surface scouring. More recently, the engineering advances have been concerned with modifications of filter media that would allow greater production of high quality water from a given filter area.

The evolution of filter design is illustrated in Fig. 9. The cross-section shown at the top represents the rapid-sand filter which is in common use in many filter plants today. Typical effective size of the media used is 0.5 mm although effective sizes from 0.35 to 1.0 mm have been used. During filter backwashing, the sand grades hydraulically with the finest particles rising to the top of the bed. As a result, most of the material removed by the filter is removed at very near the surface of the bed. Only a small part of the total voids in the bed are used to store particulates and headloss increases very rapidly. When secondary effluent is being processed, the high solids concentration will blind the surface in a very short time. As much as 75-95% of the headloss, under these conditions, will occur at the upper 1-inch layer of the filter. Filter runs will be so short as to be prohibitive. Further, floc breaking through the topmost layers, have increased opportunity to pass through the entire filter since voids become increasingly larger with increase in depth.

One approach to increasing the effective filter depth is the use of a dual media bed using a discrete layer of coarse coal above a layer of fine sand. The filter provides basically a two-layer effect to achieve increased penetration of particles. The amount of sand is reduced to afford lower headlosses at the higher throughput rates used. Normally, such a bed is designed so that 24 inches of anthracite coal, with a nominal size of about 1 mm, overlays a 6 inch sand layer with a size of about 0.45 mm. Hydraulic stratification still occurs following backwashing but the difference of specific gravity is such that the larger coal remains on top of the sand. The bulk of filtration is accomplished in the upper layers of the coal and at the top inch or two of the sand bed.

With low applied turbidities and constant rate operation, the coal-sand media bed has demonstrated an ability to operate in the range of 4-5 gal/min/sq/ft of filter surface area. A defect in this design is that if a flow change occurs, the particles held in the relatively large void volume of a coal bed, can become dislodged and will be captured by the fine layer of sand and the filtration run would have to be terminated either because of high head loss at the coal-sand interface or because of breakthrough of particles through the relatively shallow sand bed. This design, then, presents a serious inconsistency in design.

Ideally, the effluent should pass through as fine a filter material as is feasible. This ideal design is illustrated in the bottom cross-section of a filter uniformly graded from coarse to fine from top to bottom.

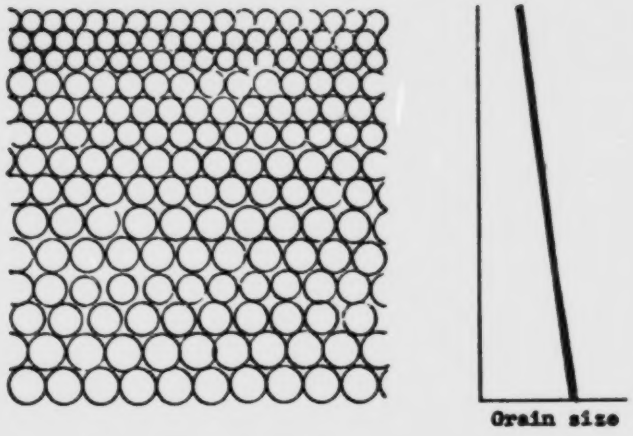


Figure 1
Cross-Section Through
Single-Media Bed
Such as Conventional
Rapid Sand Filter

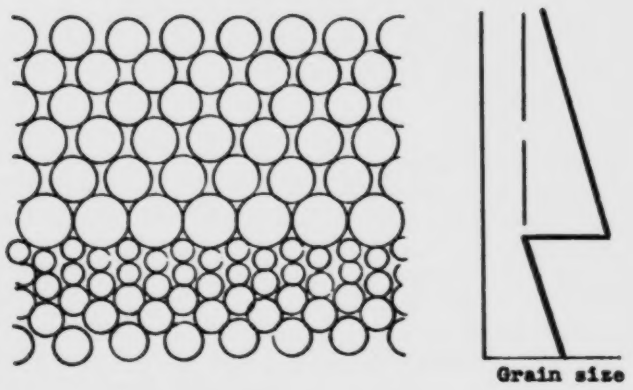


Figure 2
Cross-Section Through
Dual-Media Bed
Coarse Coal Above
Fine Sand

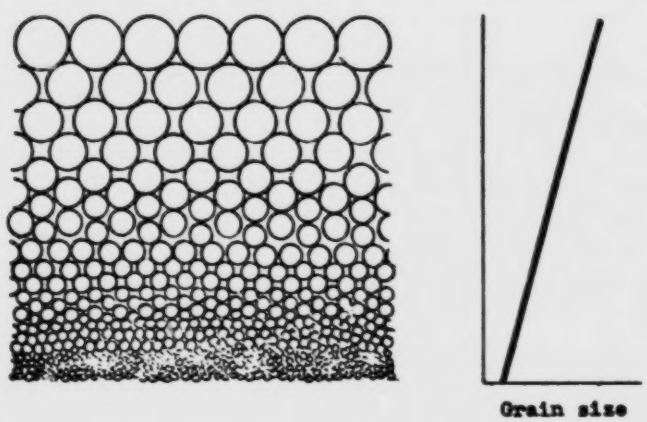


Figure 3
Cross-Section Through
Ideal Filter
Uniformly Graded From
Coarse to Fine
From Top to Bottom

FIG. 9

One solution is the use of three materials of differing specific gravity of such size gradation that some intermixing of the materials occur at the interfaces of the bed layers. The third media material is garnet which has a specific gravity of about 4.2. An ideal filter bed, then, would consist of about 60% of anthracite with a size of 1.0 to 1.5 mm at the top, 30% sand with a size of 0.4 to 0.5 mm at the middle and 10% of garnet with a size of about 0.15 mm. The materials are so sized that intermixing occurs at the interfaces. In this ideal filter, the effluent is passed through increasingly finer media. The uniform decrease in media particle size with filter depth allows the entire filter depth to be used for floc removal and storage.

Cost of the filtration step is shown in Fig. 10. For a 10 mgd plant this cost amounts to about 3.5¢/1000 gallon, when operating the filter at 4 gpm/sq ft. Further economy, of course, can be obtained at higher rates. Rates as high as 6-8 gpm/sq ft have been shown to be feasible when proper pretreatment of coagulation-flocculation followed by sedimentation is practiced.

Moving Bed Filter Technique

A new filtering technique has been evaluated by Johns-Manville under contract with FWQA. The technique is designed to overcome the problem of surface clogging and to achieve what is obtainable by multi-media filtration. A schematic diagram of the moving bed filter is shown in Fig. 11.

The unit is basically a sand filter. Particulate matter is removed as the water passes through the sand (0.6 to 0.8 mm). As the filter surface becomes clogged, the filter media is moved forward by means of a mechanical diaphragm. The clogged filter surface is removed either hydraulically or, as shown, mechanically thereby exposing a clean filter surface. The sand and accumulated sludge is collected and washed. The sand is returned via a hopper to the base of the bed. The unit is thus a form of countercurrent extraction device feeding sand countercurrent to the water being filtered. The moving bed filter has a renewable filter surface analogous to the microstrainer and the advantage of depth filtration comparable to the coarse media filter. The unit does not have to be taken off-stream for backwashing. In theory, 1% of the filter is being backwashed 100% of the time compared to the conventional practice of backwashing 100% of the filter 1% of the time.

Several pilot MBF units have been built to date and used to treat settled and non-settled trickling filter effluents and primary effluent. The system lends itself well to the use of chemical aids ahead of filtration because of designed flexibility to handle high solids loadings.

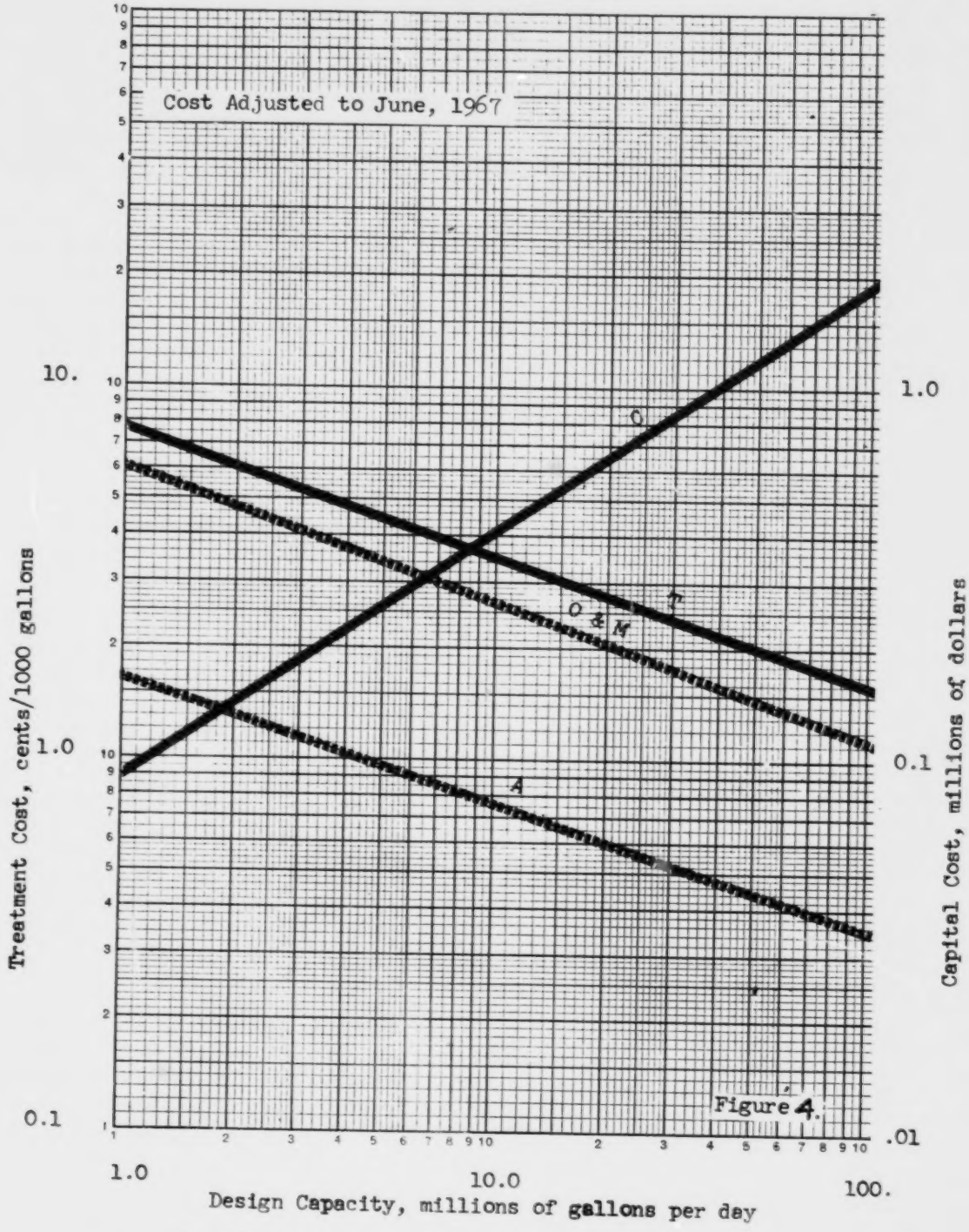
Figure 10

FILTRATION THROUGH SAND OR GRADED MEDIA - 4GPM/SQ FT

Capital Cost, Operating & Maintenance Cost, Debt Service

vs.

Design Capacity



C = Capital Cost, millions of dollars
A = Debt Service, cents per 1000 gallons(4 1/2% - 25 yr.)
O & M = Operating and Maintenance Cost, cents per 1000 gallons
T = Total Treatment Cost, cents per 1000 gallons

FIGURE 11

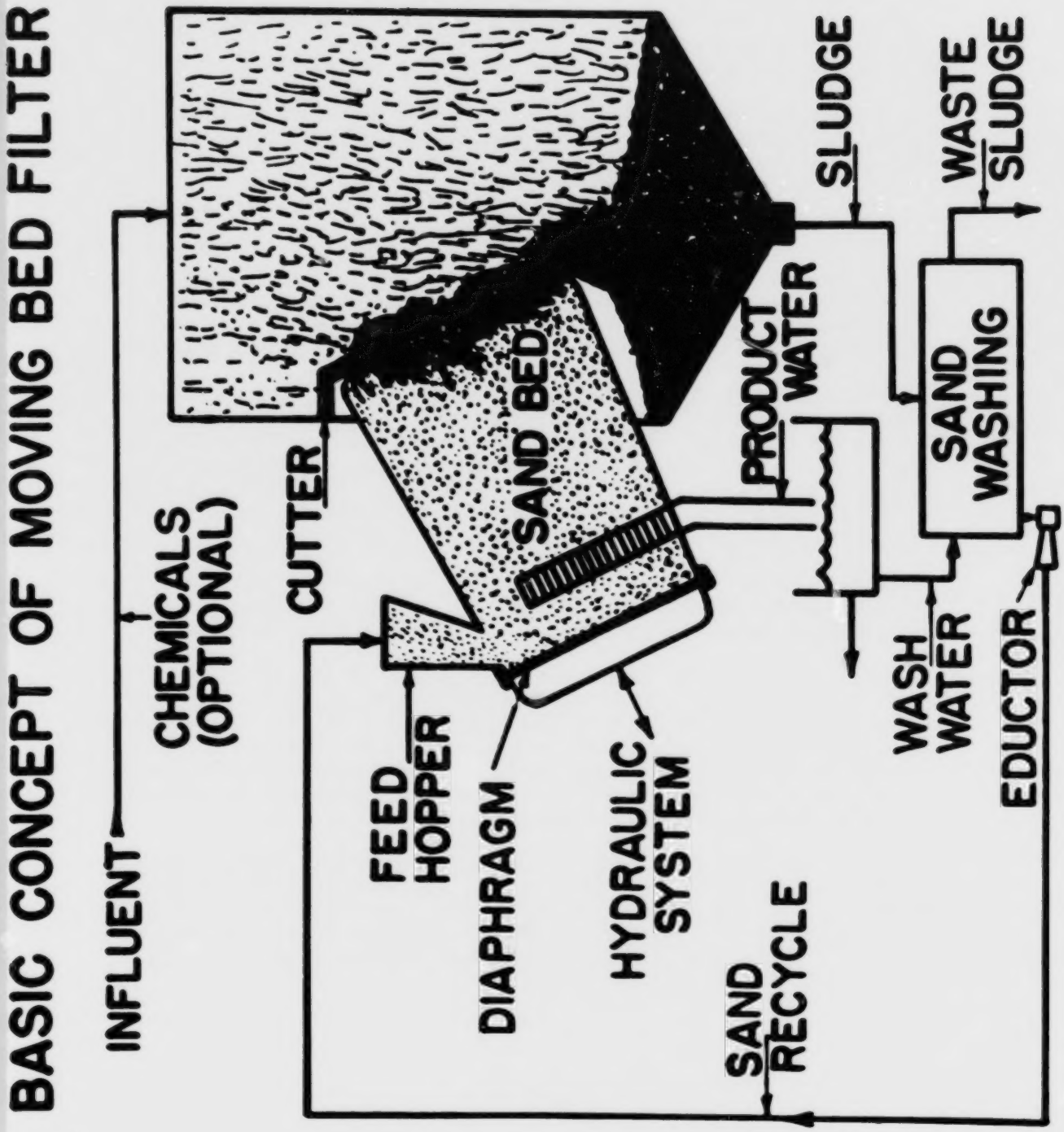

BASIC CONCEPT OF MOVING BED FILTER
INFLUENT
CHEMICALS (OPTIONAL)
CUTTER
SAND BED
FEED HOPPER
DIAPHRAGM
HYDRAULIC SYSTEM
SAND RECYCLE
PRODUCT WATER
SLUDGE
SAND WASHING
WASH WATER
WASTE SLUDGE
EDUCTOR

Fig. 12 shows some data with the MBF treating non-settled trickling filter effluent with various dosages of alum and coagulant aid. Product quality was maintained at about 10 BOD while being fed an influent with a widely varying BOD content of ≈ 40 to as high as 180 BOD.

It is too premature to talk about cost of this method of filtration. Design and performance information developed from these pilot units will be used to obtain these costs.

ULTRAFILTRATION

One of the newest unit processes to separate solids from liquids is the operation known as ultrafiltration. While this method has been under development over the past 10 years, it is only within the past two-three years that has seen the commercial development of this process.

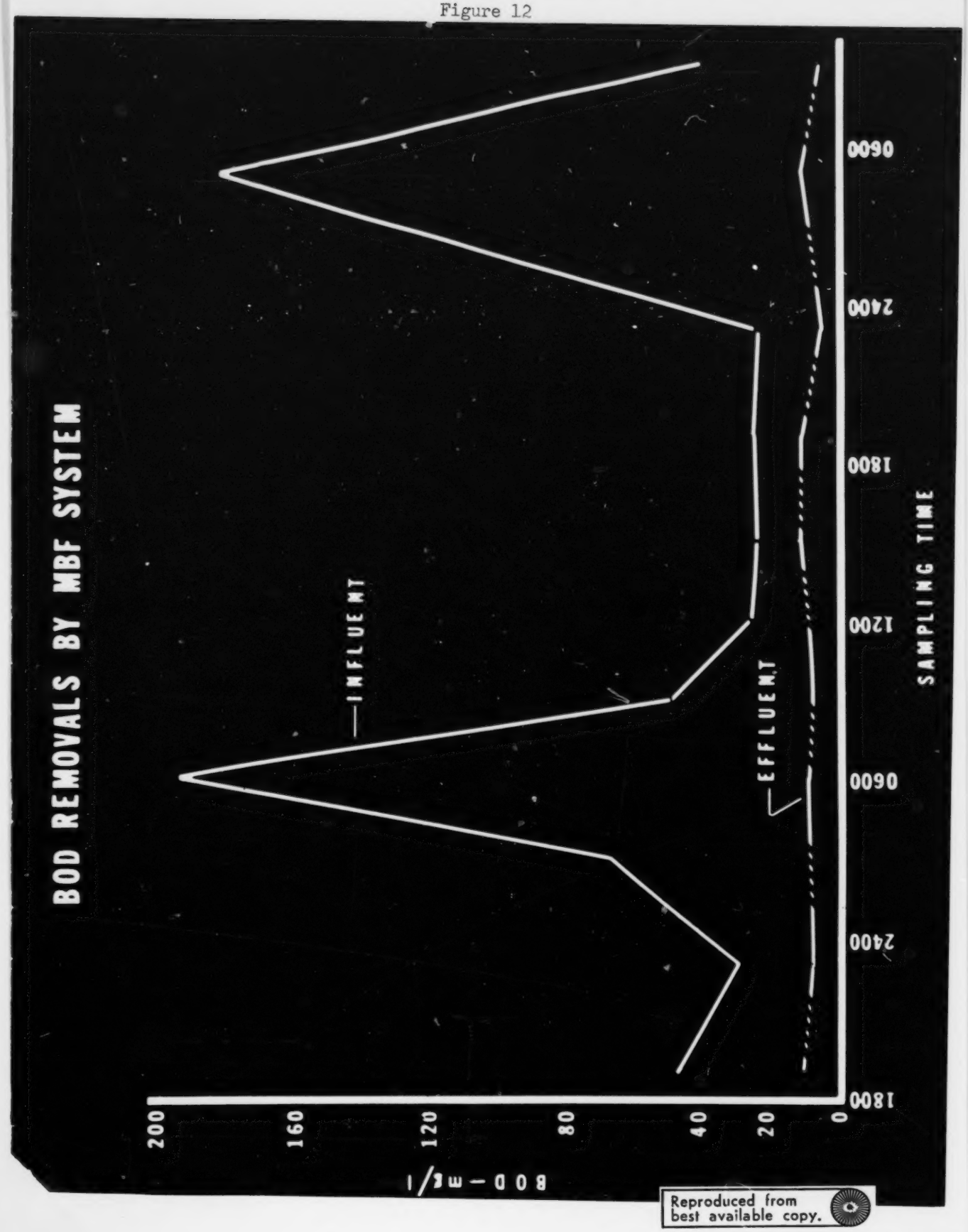
Ultrafiltration is closely related to reverse osmosis with the distinction generally made on the basis of size of particle separated. Reverse osmosis removes all molecular sizes including inorganic salts. Ultrafiltration generally will not separate molecules smaller than ≈500-1000 MW, thus inorganic salts are not separated from solution. Ultrafiltration uses pressures of about 50 psi in contrast to reverse osmosis where pressures in excess of 500 psi are generally used.

Membrane ultrafiltration is a pressure activated process using semi-permeable membranes which act as molecular screens to separate molecular and colloidal materials dissolved or suspended in a liquid phase.

Thus far, the principal commercial applications of the process have been in (1) industrial operations where valuable products can be recovered by separation from a bulk solution, (2) analytical application which provides a new method to separate molecules according to size and molecular weight, and (3) in a package waste treatment plant which separates mixed-liquor solids from a biological reactor. Solids are returned to the aerator and clarified product water is discharged.

A plant employing ultrafiltration has been installed on Pikes Peak to provide waste treatment and water reuse. The essentials of the process are shown in Fig. 13. The 15,000 gpd plant treats wastewater by high-solids activated sludge. The solids are separated in an ultrafiltration unit. Solids are returned to the aerator. Product water is excellent. Some typical removals are shown below.

Figure 12



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ENZYME REACTOR

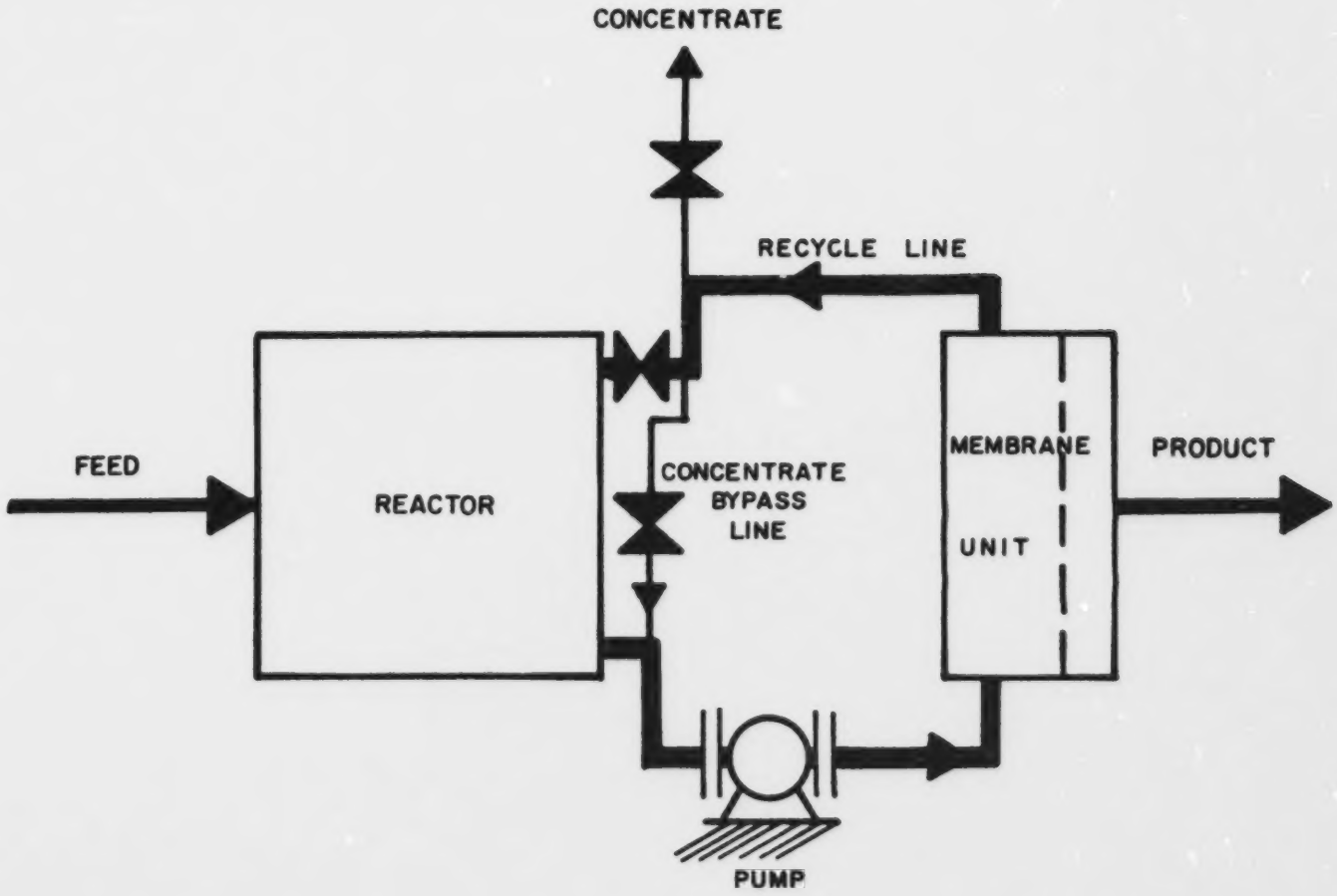

FIG. 13 REACTION SYSTEM

Removals by Activated Sludge and Ultrafiltration

	Influent	Effluent	% Removal
BOD	382	<1	>99
COD	678	20	97
Turbidity	-	<0.1	-
SS	323	0	100
PO_4-P	12.2	7.7	37

These results emphasize that only molecules or particles greater than 500-1000 MW are separated. Inorganic ions such as phosphate are not retained. The 37% reduction of phosphate was due to biological uptake in cells which were removed.

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THE PORTEOUS PROCESS

BY

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DEPARTMENT OF PUBLIC UTILITIES

November 1970

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THE PORTEOUS PROCESS

In January of 1969 the City of Colorado Springs started a program of sludge conditioning with the Porteous Process. This process is based on the work done by W. K. Porteous during the early 1900's with batch process, in England.

Process operation is based on the Heat Syneresis principle. An organic sludge gel is a colloidal system incorporating within its structure large amounts of water. The structure is made up of cell walls containing cell water, and both soluble and particulate matter. Outside the cell is a gelatinous sheet composed of protein and carbonaceous material along the surface water. By heating the sludge, the cells rupture and release the entrained liquor. This phenomena is based on time and temperature, and the expulsion of the liquid from the gel is termed SYNERESIS.

After the collapse of the colloidal structure, the aqueous solution can be separated from the solids by decanting, and the solids processed by vacuum filtration, centrifuges, or presses.

The sludges now being processed in Colorado Springs are composed of 70% raw material, 10% secondary sludges, and 20% digested material. The primary raw and secondary are blended in the primary clarifiers and pumped directly to the Porteous unit; the digested sludges flow only

when the pumps are not in operation from the primary clarifiers. The material now flowing from the digesters cannot truly be classed as digested since pH range, volatile acids, and alkalinity are out of the normal range of good digester operation. Instead, the material could be classed as thickened septic sludge which is only being held for heat processing. This, however, does not pose a problem, and the ultimate goal of operation is to empty the digester completely.

One of the major questions asked about the Porteous unit is, "Do sludges in the septic range, or any other configuration, cause treatment problems?" The answer so far has been, "No." It has been quite apparent in the Springs' operation that heat syneresis can be applied to any type of sludge and many other organic waste slurries. The process, being physical, is not affected by sludge type, chemical waste, or other toxic matter which so drastically affects conventional digestion systems.

Another question is, "How does the process affect filterability?" It has been determined that processed sludges where the specific resistances have been lowered to 40×10^7 sec/gm (1) will produce acceptable filterability. The Porteous produces material easily below 10×10^7 sec^2/gm, and in the Colorado Springs operation, specific resistance of 1.0×10^7 are normally found. This allows operation on vacuum filtration of 15 lbs. D.S./hr/sq.ft. of area at a moisture content of 62%. This high yield has produced two beneficial operation results. The first is the fact that two vacuum filters installed in 1965

to handle a sludge load from 20 mgd flow have been increased to 55 mgd. The second is land area for drying; under normal digester operation 24 acres had been used for beds -- with chemical treatment, this area had been reduced to 12 acres, but handling the sludges with heavy equipment was almost impossible since the material refused to dry. With the Porteous system, this area has been reduced to less than 4 acres, and piles of sludge up to 25 feet in height have been accomplished.

Another question asked is, "Does the sludge tend to reverse?" The answer to this is, "No." Since the material is heated to a point where all known pathogenic bacteria and seeds are sterilized, the material therefore, unless seeded from an outside source, remains essentially the same.

The Colorado Springs operation was built under the European flow-pattern, utilizing sludge-to-sludge heat exchange in a double-tube system. Upon startup the raw material was run through the interior tube, with the cooked material in the outside tube. After 194 hours of operation, plugging occurred, and the flow was reversed, with the raw on the outside and cooked on the inside, and again plugging occurred. Upon investigation of the sludges, it was decided that the rag content was much higher then the normal European sludges, and a water/sludge system was set up. (Figure 1.) Under this system the raw material is carried in the inside smooth tube, and water heated by the cooked sludges is recirculated in the outer tube for heat exchange.

Total process per day in this unit is approximately 108,000 gpd with an average solids range of 5%. This handles the full amount of raw material received and allows continuous removal of stored sludges in the digesters.

Probably the most maligned area of heat treatment is the production of so-called HEAT TREATMENT LIQUOR (HTL). The biological load imposed by this liquor can be treated the same as the load imposed by supernatant liquor from a digester. It is truly not an additional load but part of the function of treating wastes. However, in most installations that have been made, the design engineer would rather treat it as an imposed load, which can be summarized as follows:

$$Hs - Is = ds$$

or

$$Hs = Kds + Is$$

Where:

Hs = Strength of heat treatment liquor in BOD Mg/l

ds = Dissolved solids on ash-free basis in mgl

Is = Initial strength of supernatant in BOD_5 mgl*

K = Imposed BOD_5 per mgl of dissolved solids

*BOD_5 In the breakdown of the sludge structure a proportion of the organic matter is hydrolyzed, leading to an increase in the biological load of the sludge liquor over and above the initial supernatant strength. From a series of tests using sludges from different sources and

varying solids content, it would appear that a direct relationship can be established for the BOD_5 load imposed in relation to the milligrams-per-liter of solids taken into solution. (2)

At the Colorado Springs plant, a computer-run on eight months of operation set up a loading factor of from 8% to 10% of the influent BOD as an additional loading on the plant, not taking supernatant into consideration. (3)

In the operation of a plant, probably the worst problem with the HTL is the immediate odor while it remains hot from the heat exchanger and reactor process. This, however, drops quite rapidly as cooling takes place.

It has also been experienced that the BOD_5 is readily biodegradable and can be reduced over high-rate filters with no problems apparent. Future plan for this material is to add it to flow to the proposed activated-sludge plant, which also seems to have an excellent removal system for this type of material.

COST FACTORS

In the Colorado Springs plant, cost per ton of dry solids runs approximately $2.10 without labor and amortization; with these factors, cost is approximately $10.60 per ton. Trying to set a figure that would cover all installations is impossible since cost factors at each

installation would be different. We do know, however, that our costs have dropped sharply from chemical sludges, which ranged from $18 to $25 per ton of dry solids, for lime and ferric alone. The other plus factors, which have not been figured in dollars, are land saving and time saving.

IN CONCLUSION, heat treatment in Colorado Springs has been an excellent asset to the operation. The mechanical difficulties that have been encountered have been far outweighed by the Process operation in producing dried sludges of a stable nature without the problems found in standard biological digesters.

JDP:rb
Att: Acknowledgements
Figure 1.

ACKNOWLEDGEMENTS

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F. Lussignea — Water Pollution Research
R. Bakersville — London, September 1962

(2) K. G. Mulhall - Associate
B. D. Nicks — Discussion by the East Anglian Branch of the Institute of Water Pollution Control on Heat Treatment

(3) Gene Suhr
CH_2M
Corvallis, Oregon — Predesign Report
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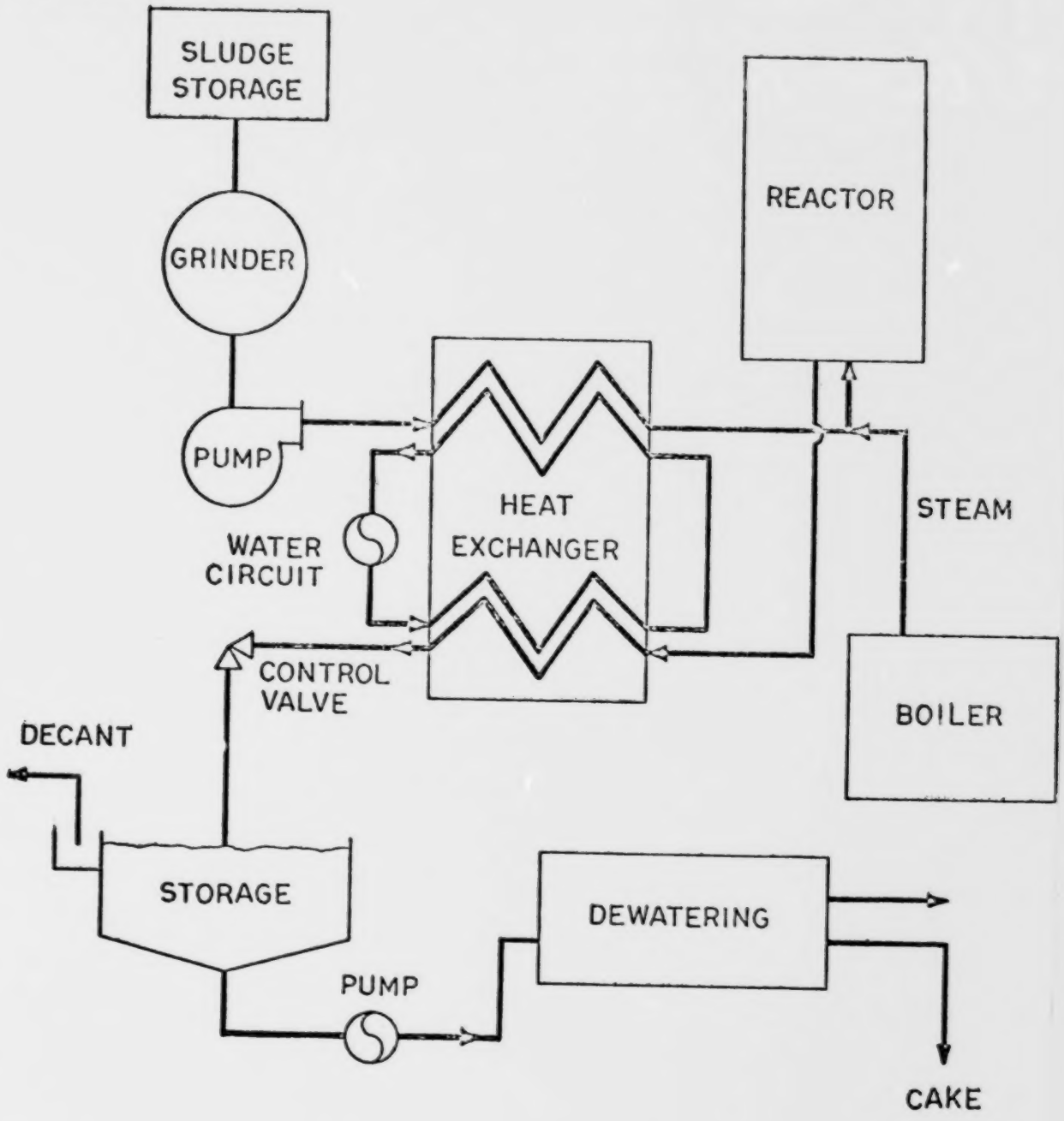
Colorado Springs, Colorado
June 1970

Figure 1 — BSP Corporation

* * *

FIGURE 1

BSP CORPORATION
AN ENVIROTECH COMPANY



SCHEMATIC DIAGRAM OF PORTEOUS PROCESS

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4-1

DEMINERALIZATION OF WASTEWATERS

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Dallas, Texas

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DEMINERALIZATION OF WASTEWATERS

Jesse M. Cohen

I. Introduction

A. Today's best conventional waste treatment processes were not designed to remove non-biologically degradable organics or inorganic salts. It appears certain that improved wastewater treatment will be based on the addition of physical-chemical separation processes to the current biological processes.

B. Degree of treatment required of a renovation process will be determined by the specific purpose for which the water is intended.

C. For certain industrial use and for deliberate municipal recycle, it will be essential to reduce the salt content of wastewater.

D. Need for demineralization is based on the fact that each water-use cycle results in an incremental addition of dissolved inorganic salts.

1. Average values for mineral increments through one municipal use are shown in Figure 1.

2. Increase of total dissolved solids ranges 100-500 mg/l.

3. Most important increments, in terms of magnitude, are sodium, sulfate, bicarbonate, and chloride.

E. Three principal methods are in varying stages of development designed to restore the mineral quality of sewage effluent to at least the quality of river water or better.

1. Electrodialysis

2. Reverse Osmosis

3. Ion Exchange

II. Electrodialysis

Electrodialysis is useful for partial demineralization of low mineralized waters, preferably not exceeding 2000 mg/l of TDS. Since municipal wastewaters generally do not exceed 1000 mg/l, this process is applicable.

A. Principles

1. Principle of operation of an electrodialysis unit is shown in Figure 2. When a direct electric voltage is impressed across a cell containing mineralized water, the positively charged ions (cations) migrate to the negative electrode and the negatively charged ions (anions) migrate to the positive electrode. If cation and anion-permeable membranes are placed alternately between the electrodes, alternate compartments become more concentrated in salts while the intervening compartments become more dilute.

2. Multiple compartments can be interconnected by manifolds which produce two products, one low in dissolved solids, one concentrated. Figure 3.

3. Membranes are composed of ion-exchange materials. The driving force for the migration of ions from solution to the membranes is electrical energy.

B. Operating problems

1. Stagnant films at the membrane surfaces lead to concentration gradients producing scaling from precipitation of compounds with low solubility.

2. Electrolysis of water, which produces hydrogen and hydroxyl ions, leading to increases in power consumption.

3. Deposition of colloidal negatively charged particles on the anion membrane causing fouling and decrease in demineralization.

C. Pilot plant operation

1. Experimental electrodialysis equipment was investigated, Figure 4, with the following conclusions:

a. To maintain operation, the secondary effluent had to be pretreated for removal of organics by activated carbon and clarified by alum coagulation,

b. pH of the concentrate stream was held at 5 or less to prevent calcium carbonate scale formation,

c. Operation was very sensitive to fouling by colloids. Figure 5.

(1) Extended operation could be maintained only by reducing turbidity to 0.03 JTU. Higher turbidities produced short runs.

(2) Biological growth on the membranes contributed to fouling.

(3) Recovery from fouling could be obtained by shutting down for a day or so.

d. Blow-down amounted to about 10% of the product to prevent scaling.

2. Electrodialysis removes ions to varying degrees. Figure 6.

a. Selectivity for ions varies with time and with degree of fouling. Both phosphate and sulfate removal rates were affected.

3. Volume of waste concentrate will amount to $\approx$ 10% of product and methods for disposal of this concentrated waste must be found.

4. Firm costs for electrodialysis are not available. For a 10 mgd plant, capital cost to produce partially demineralized water from wastewater has been estimated at 0.34 dollars per gallon per day and operating costs at 16.1 cents per 1000 gallons. No provision is made in these costs for pretreatment and disposal of brine.

III. Reverse Osmosis

The theoretical capability of reverse osmosis to remove in excess of 90% of the inorganic ions, organic matter and colloids (bacteria and virus) makes this process an important discovery.

A. Principles

1. Figure 7. In normal osmosis when two liquids of differing salt concentrations are separated by a semi-permeable membrane, water will flow from the dilute solution to the more concentrated. Driving force is the concentration gradient.

2. In reverse osmosis pressure, in excess of the osmotic pressure, is applied to the concentrated side causing the normal flow of water to be reversed; i.e., from the concentrated to the dilute side of the membrane.

3. Keys to the successful application of reverse osmosis to wastewater reclamation are:

a. Development of a membrane capable of reasonable service under operating conditions,

b. Proper incorporation of the membranes into a system to maximize product flow at minimum cost.

B. Membranes

1. Practical reverse osmosis was achieved when Loeb and Sourirajan in 1960 developed a modified cellulose acetate membrane capable of water permeabilities some 500 times greater than earlier films.

2. Membranes consist of two distinct layers. One a spongy porous material which accounts for 99.8% of the thickness and an active layer which accounts for all of the separation of contaminants. Figure 8. Surface layer is typically 0.25μ thick, porous layer 100μ thick.

3. Original theory of operation considered a "straining" mechanism. Current theory is that water molecules dissolve in the membrane material and then diffuse through it. Inorganic ions have lesser solubility in the membrane and have restricted mobility.

C. Water throughput-flux

1. Flux is defined as the flow of water through a membrane, measured in gallons per square foot per day.

2. Flux is directly proportional to applied pressure - minus the osmotic pressure - and inversely proportional to thickness of membrane.

3. Relationship of pressure and salt rejection (solute retention) are shown in Figure 9.

a. At low pressures, low flows and little salt removals are obtained,

b. As pressure exceeds osmotic pressure, flow and salt rejection increase and 100% salt rejection is approached asymptotically.

4. Fluxes in the range of 20-40 gfd are required to make RO economically attractive. Current fluxes of ≈ 10 gfd at 750 psi are common.

5. A major current problem is the inability to maintain flux because of fouling and chemical and physical changes that occur in the membrane.

D. Materials rejected

1. Inorganic salts are rejected in amounts exceeding 90%.

2. Organic molecules, with the exception of certain low molecular weight materials like amines, alcohols and acids, are removed.

3. Suspended and colloidal materials including bacteria, virus and sewage colloids are completely removed.

E. Membrane separator design

A key factor in practical operation of RO is the mechanical design of the unit.

1. Plate and frame, using flat membrane sheets in a device similar to a filter press was one of the earliest designs. Figure 10.

a. Units capable of producing 100,000 gal/day have been developed by Aerojet-General. Largely used for brackish water treatment.

2. A simple tubular design consists of porous tubes which are lined with cellulose acetate membranes. Design is similar to heat exchangers. Flow is from inside the tubes at pressure and discharged from the outside surfaces of the tubes at ambient pressure. Figure 11.

3. To obtain a maximum of membrane area in a small volume, a "spiral-wound" design was developed by General Atomics. Several hundred feet of membrane can be accommodated in a cubic foot of pressure vessel volume. Figure 12.

4. The ultimate in greatest area per unit volume is approached by "hollow-fiber" design.

a. About 20 million hollow fibers can be packed into a shell 1 foot in diameter and 7 feet long.

b. A 12-inch permeater 7 feet long contained in a unit only 5.5 cu.ft. in volume provides about 50,000 square feet of membrane surface and will produce 7500 gal/day.

c. Flux with these fibers is small - currently about 0.15 $gal/ft^2/day$. Fluxes of 1.5 gfd may be attainable but this will still be 1/10 that obtainable with other designs.

d. This configuration can be characterized as "very high surface area, low flux permeater."

F. Cost

Application of RO to wastewater is still in early stage of development.

1. Based on experience in treating brackish water, cost estimates have ranged from 30-60 cents/1000 gallons.

2. These problems remain to be solved before RO can be successfully applied to wastewater.

a. Increased fluxes.

b. Maintenance of flux in the face of fouling and physical and chemical changes occurring at the membrane.

c. Increased product to waste ratios. Up to 90% has been obtained.

d. Disposal of concentrate.

IV. Ion Exchange

Ion exchange has been used for many years in water treatment for softening and boiler water conditioning. Development of newer types of resins which are not fouled by organics and newer techniques of using these resins demonstrate that ion exchange is a practical method for demineralization of wastewater.

A. Principle

1. Ion exchange materials, both natural and synthetic, are absorbents which carry charged ionic groups. To maintain electroneutrality, each ionic site must have associated with it an ion of opposite charge (counter-ion). The success of ion exchange depends on the ability of the counter-ion to be replaced or exchanged for another ion of the same charge.

2. When all counter-ions have been replaced, the ion exchange material is exhausted. Regeneration is obtained by contacting the exchanger with a concentrated solution of the original counter-ion.

B. Classification

1. Ion exchangers are classified by the charge of the exchangeable ion. Thus acid or cationic resins will exchange cations like Ca^{++} and Mg^{++} and base or anionic resins will exchange OH^- or Cl^- anions.

2. Classification also considers the degree of dissociability of the active group. Thus:

a. Strong acid resins (cationic) contain sulfonic acid groups.

b. Weak acid resins (cationic) contain carboxyl or phenolic groups.

c. Strong base resins (anionic) carry quaternary ammonium groups.

d. Weak base resins (anionic) usually have amine groups which are only slightly ionized in the OH form.

3. A common matrix material of synthetic resins is styrene or vinyl benzene which has been polymerized and which have ranging functional groups attached. Figure 13.

a. A very wide variety of resins can be prepared to meet specific needs by varying functional groups, degree of ionization, and physical characteristics.

C. Selectivity

1. A general purpose resin will exchange any of the common ions but, in a mixture of ions, selectivity will occur.

a. For strong cation exchangers the order of selectivity is $Ca^{++} < K^+ < NH_4^+ < Na^+$

b. For weak anion exchangers the order of selectivity is $SO_4^= < HPO_4^= < NO_3^- < Cl^-$

D. Wastewater demineralization

For demineralization, both an anion and cation exchanger is required, consisting of a weak anion and a strong or weak cation exchanger.

1. For economic demineralization, these requirements for the process must be met.

a. Capability of regeneration at theoretical efficiencies using low cost acids and bases.

b. High operating exchange capacities.

c. Ease of removal of regeneration chemicals with a minimum of rinse water.

d. Long life of resin to physical and chemical attrition.

e. Waste regenerants should pose a minimum disposal problem.

E. Desal process developed by Rohm and Haas has promise for economic demineralization of wastewater.

1. One modification consists of a 3-bed design consisting of a weak anion, a weak cation and a weak anion exchanger in series. Figure 14.

a. First column converts all anions to the bicarbonate form. Removes all other anions.

b. Second column converts bicarbonates to CO_2 and removes cations.

c. Third column in OH^- form absorbs CO_2 to become the bicarbonate form. This column then becomes the first in the series after columns 1 and 2 have been regenerated with ammonium hydroxide and sulfuric acid respectively.

2. A modification more applicable to wastewater treatment is shown in Figure 15.

a. Weak anion exchanger, in the bicarbonate form, removes all anions: $SO_4^{=}$, $PO_4^{=}$, NO_3 and Cl^-.

b. Column effluent is polymer flocculated, CO_2 removed and lime softened which removes: suspended solids, Ca^{++}, Mg^{++}, and Fe^{+++}.

c. Final column, a weak cation exchanger, removes remaining cations: NH_4^+, Na^+ and K^+.

d. Exchangers regenerated with ammonium hydroxide and sulfuric acid. Calcining of lime would provide CO_2 for conversion of anion exchanger to bicarbonate form.

e. About one-half of the COD is removed by the anion exchanger and quantitatively removed by the regenerant.

f. Final product, containing residual amounts of inorganic solids - ≈ 50 ppm - and 1/2 of the original COD, could be blended with undemineralized water to reduce cost.

F. Cost

Process has not been applied on a sufficiently large scale to obtain reliable cost data.

1. Estimate for 1 and 10 mgd plants, including capitalization, equipment and chemical costs for the modified Desal process is 17-18 cents/1000 gallon.

a. CO_2 is assumed to be available.

b. Resin life estimated to 3 years.

c. No costs included for ammonium recovery and brine disposal.

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FIG. 1

AVERAGE COMPONENTS IN DOMESTIC SEWAGE EFFLUENTS

CONSTITUENT	APPROX BUILD-UP THROUGH ONE MUN USE	NORMAL RANGE OF BUILD-UP	REPRESENTATIVE SECONDARY EFFLUENT
Ca ($CaCO_3$)	30 ppm	15- 40	95
Mg ($CaCO_3$)	13	20-40	39
Na	55	40-700	84
SO_4	25	10- 40	51
CL	35	20-125	50
PO_4	30	15-40	30
NO_3	8	0- 18	8
SiO_2	15	10- 20	35
ABS	3	1- 4	3
COD	70	40- 40	70
BOD	15	9- 40	15
TDS	250	100-500	550
HCO_3	65	---	170
pH	---	---	7.5

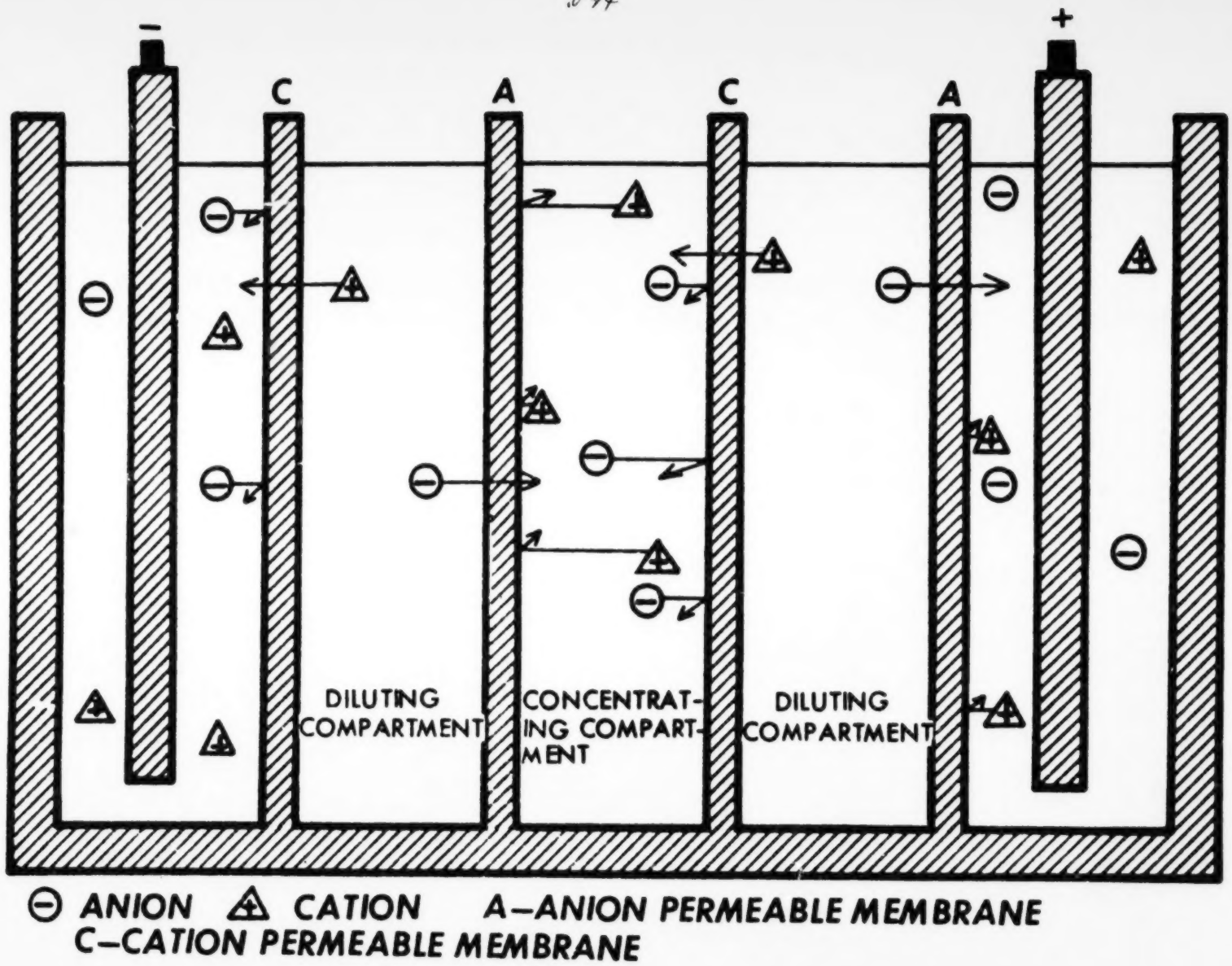

FIGURE 2 &
FIGURE 3. ELECTRODIALYSIS PRINCIPLE

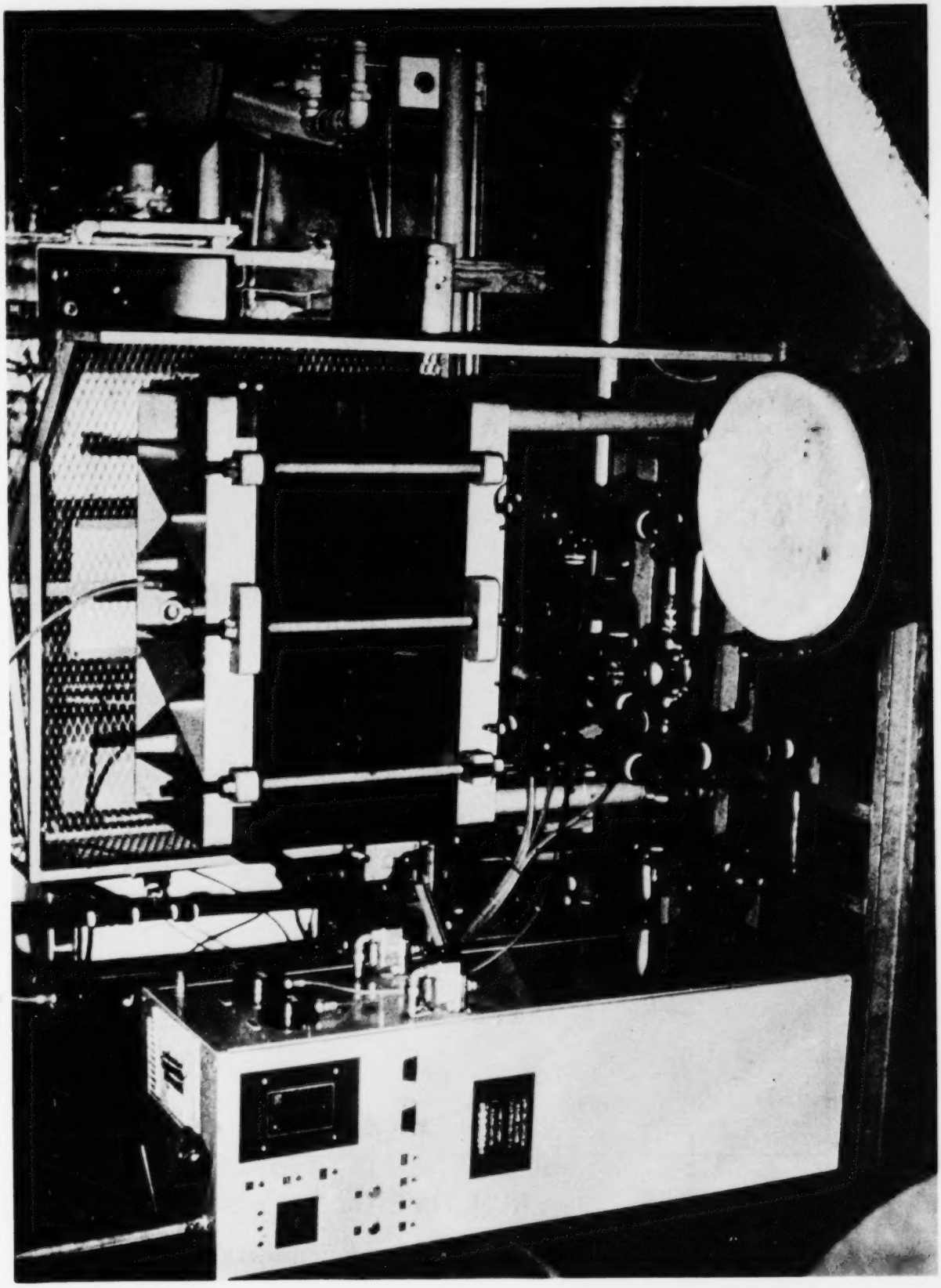

FIGURE 4

4-15

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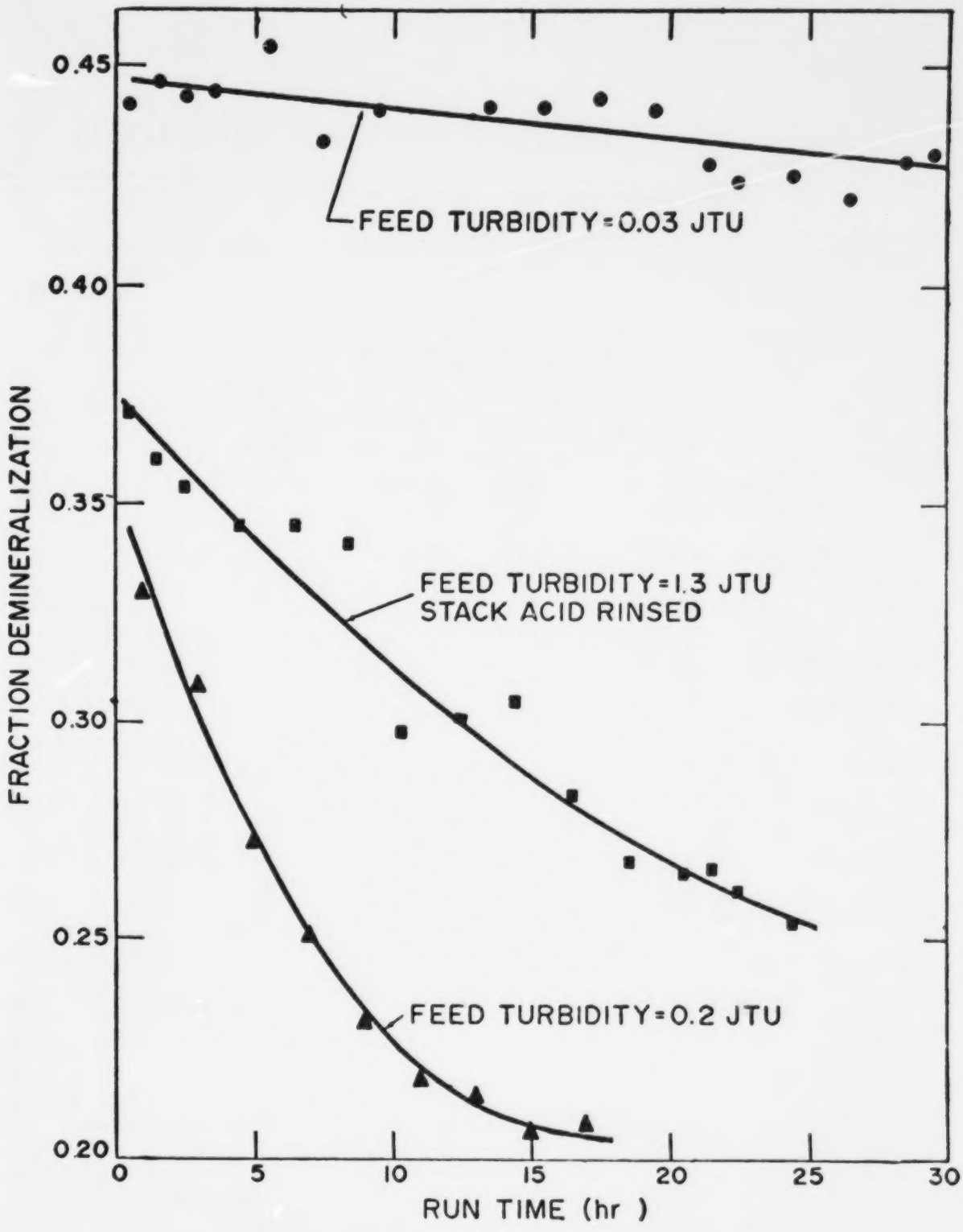
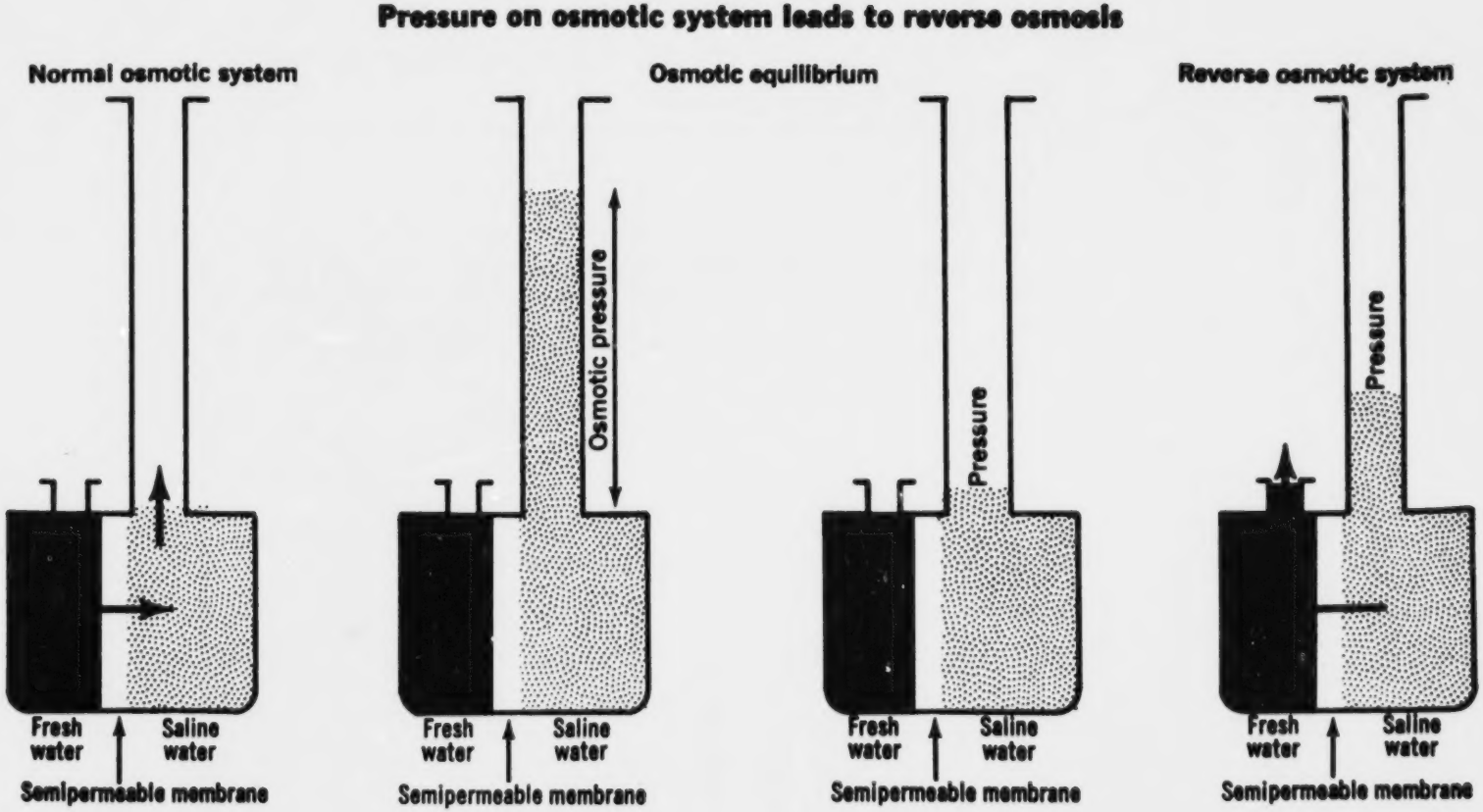


FIG. 5 **Effect of turbidity on demineralization.**

FIG. 6 **Ion Removal Selectivity**

Ion	Fraction of Ion Removed / Fraction of All Ions Removed	
	Average	Range
Bicarbonate	0.77	0.63–0.95
Chloride	1.25	1.07–1.51
Nitrate	1.22	1.02–1.48
Phosphate	0.72	0.25–1.03
Sulfate	1.11	0.21–2.00
Ammonium	1.15	1.05–1.3
Calcium	1.25	1.01–1.48
Magnesium	0.98	0.71–1.35
Potassium	1.14	0.77–1.35
Sodium	0.79	0.52–0.99
Calcium and magnesium	1.13	1.05–1.28

FIG. 7


Pressure on osmotic system leads to reverse osmosis
Normal osmotic system
Osmotic equilibrium
Reverse osmotic system
Osmotic pressure
Pressure
Pressure
Fresh water
Saline water
Semipermeable membrane
Fresh water
Saline water
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Fresh water
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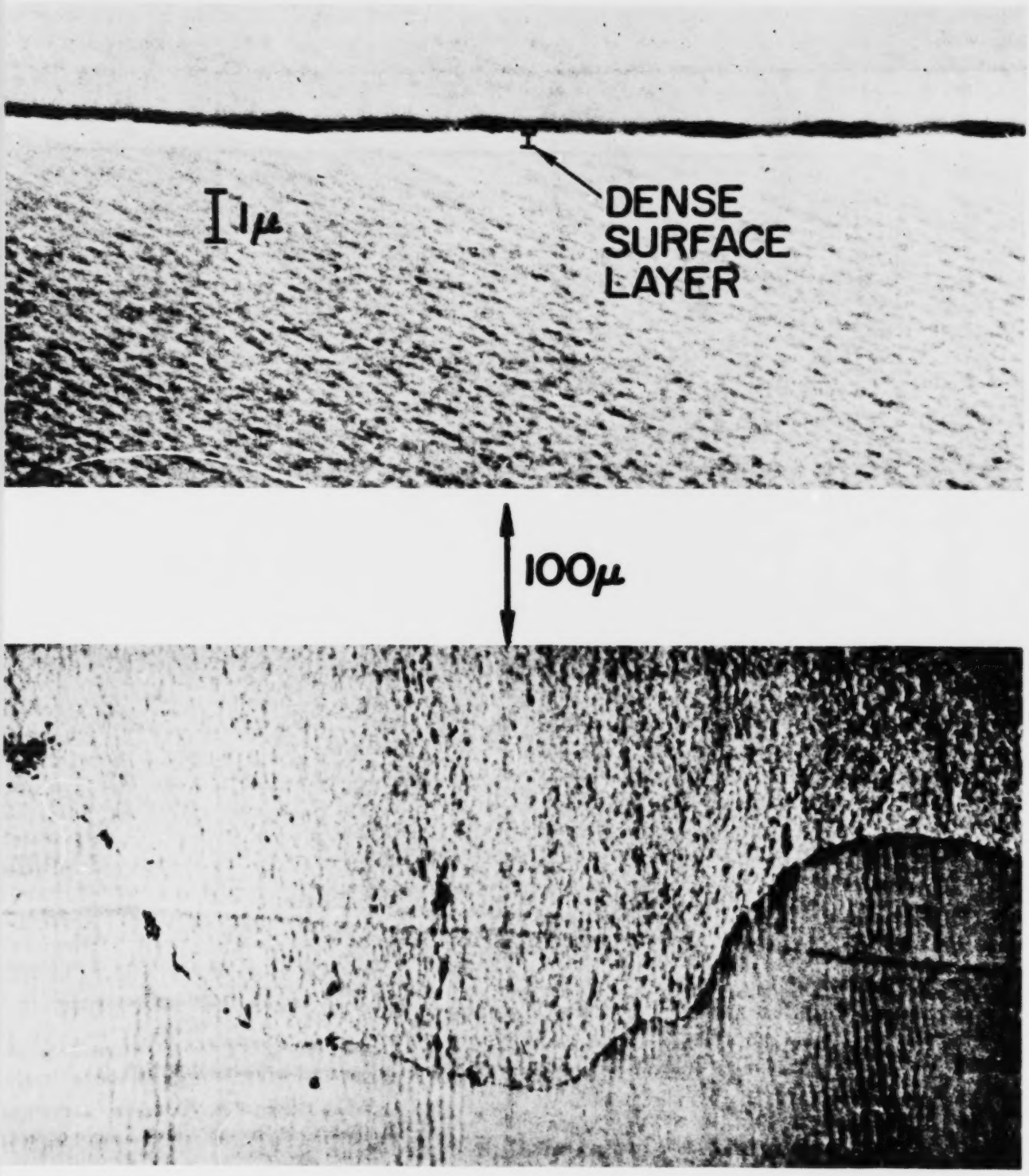


FIG. 8 COMPOSITE OF TWO ELECTRON PHOTO-MICROGRAPHS OF CROSS SECTIONS OF MODIFIED CELLULOSE ACETATE MEMBRANE

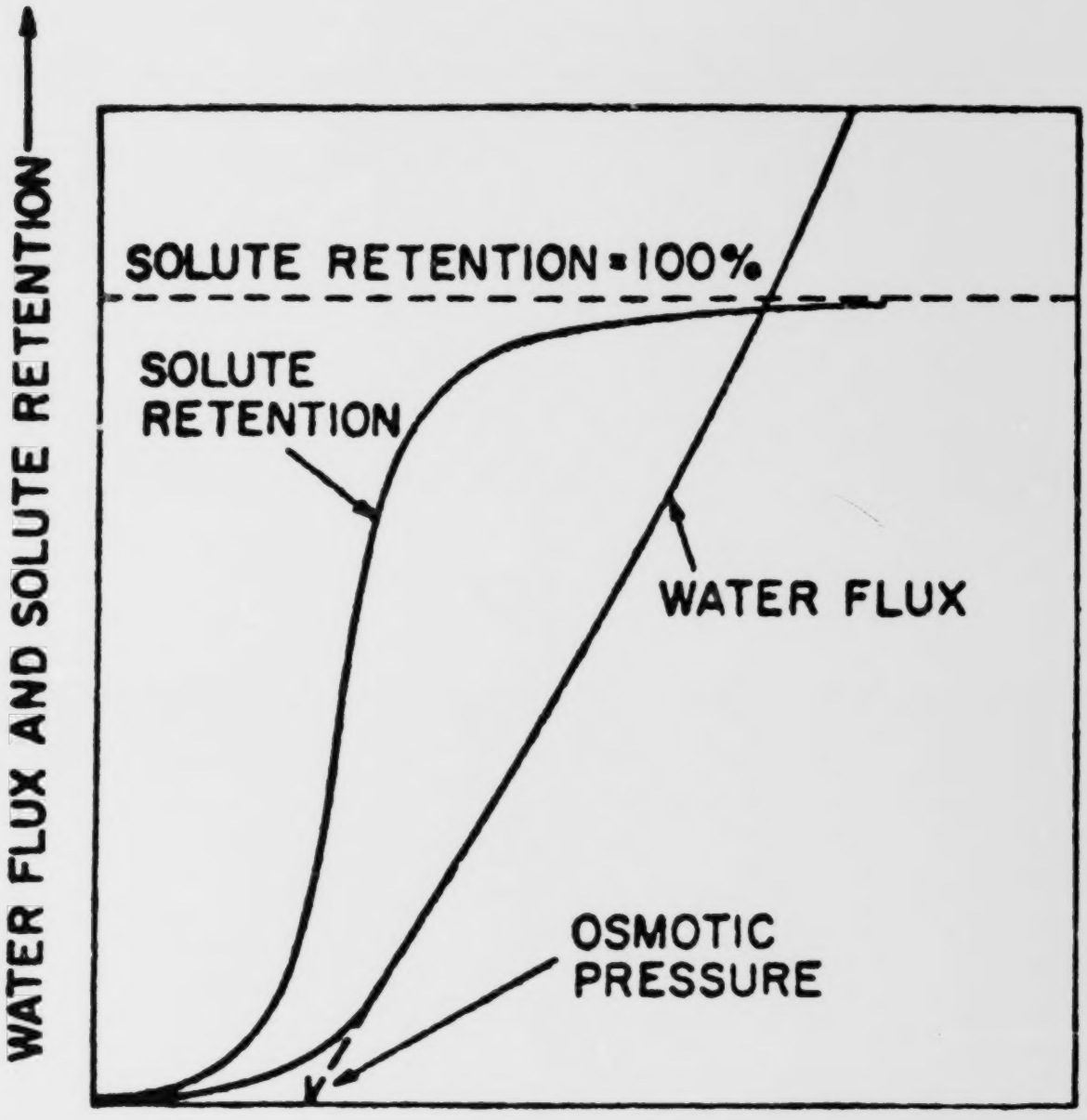


FIG. 9

Solute retention and water flux in idealized membrane.

MULTIPLE PLATE TYPE DESALINATION CELL

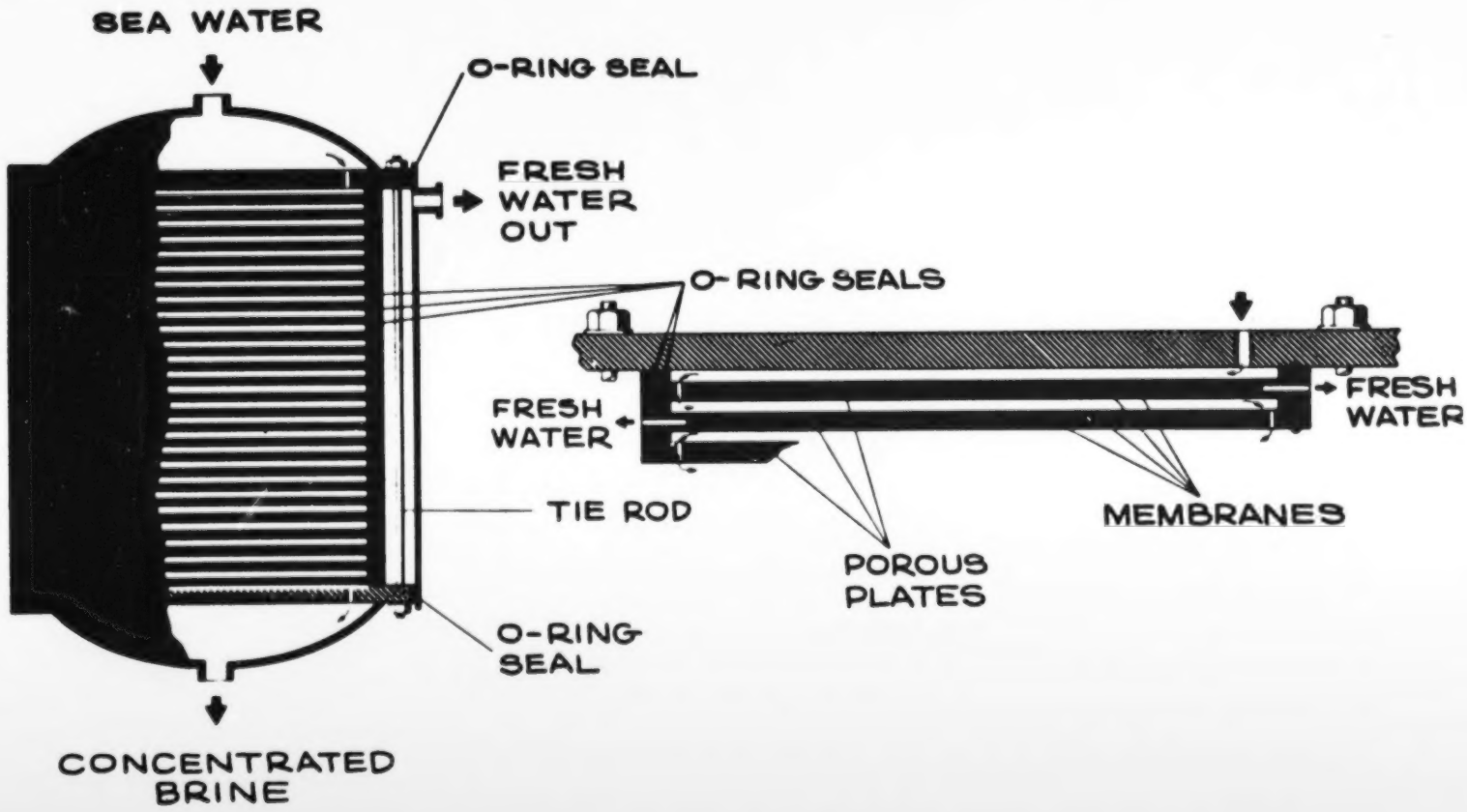
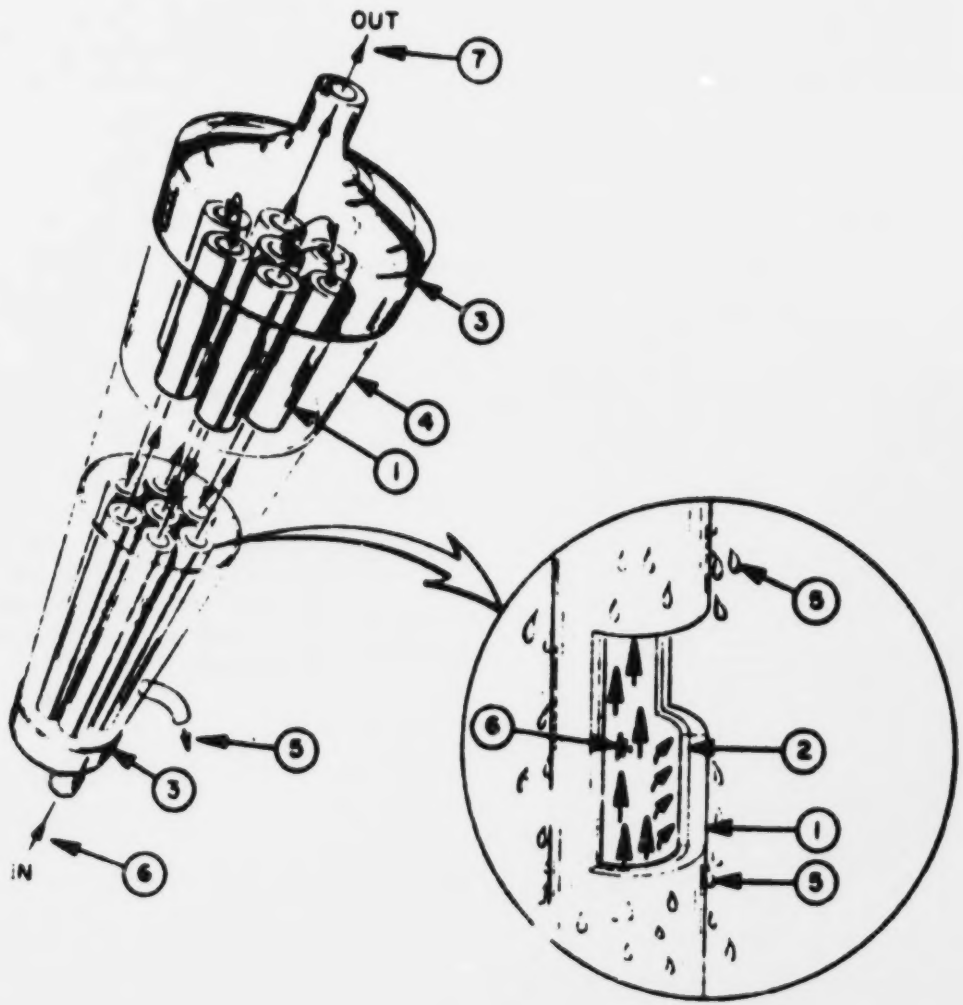
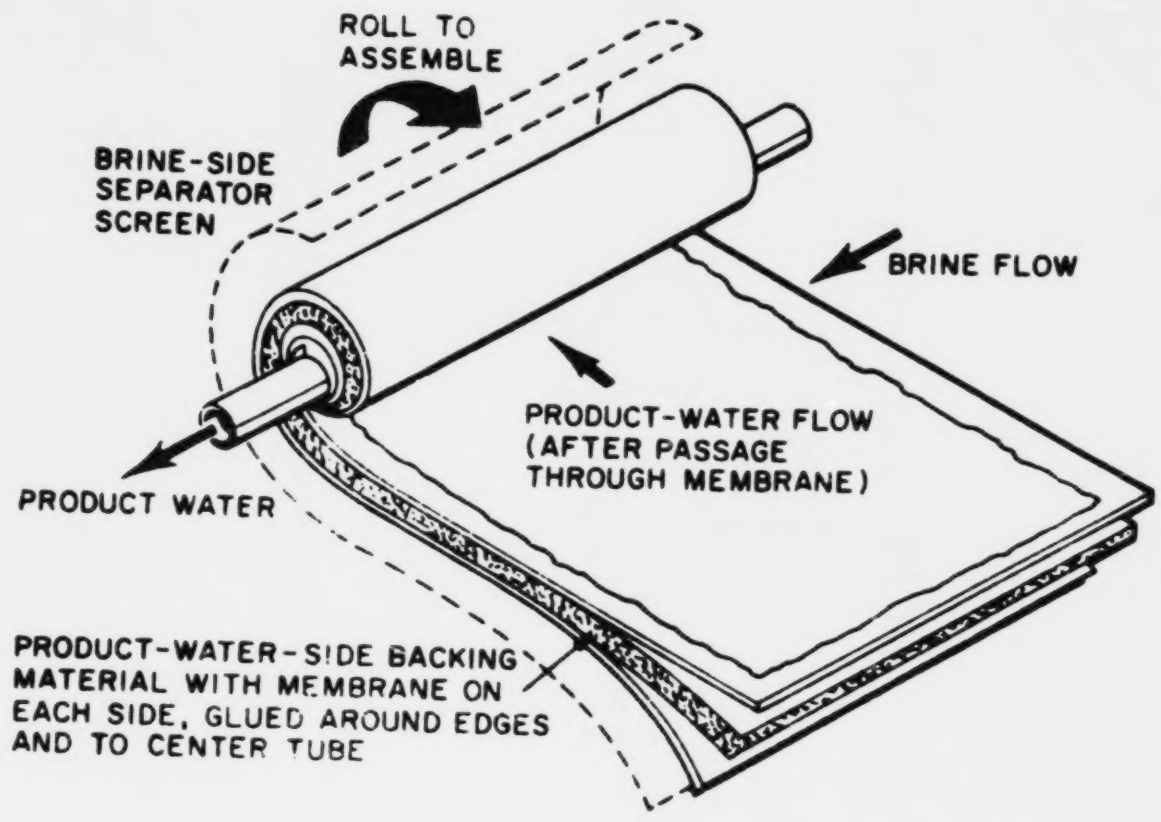


FIGURE 10



(1) FIBERGLASS TUBE
(2) OSMOTIC MEMBRANE
(3) END FITTING
(4) PVC SHROUD
to collect product water
(5) PRODUCT WATER
(6) FEED SOLUTION
(7) EFFLUENT

Figure 11. A Tubular Reverse Osmosis Unit


ROLL TO ASSEMBLE
BRINE-SIDE SEPARATOR SCREEN
BRINE FLOW
PRODUCT-WATER FLOW (AFTER PASSAGE THROUGH MEMBRANE)
PRODUCT WATER
PRODUCT-WATER-SIDE BACKING MATERIAL WITH MEMBRANE ON EACH SIDE, GLUED AROUND EDGES AND TO CENTER TUBE

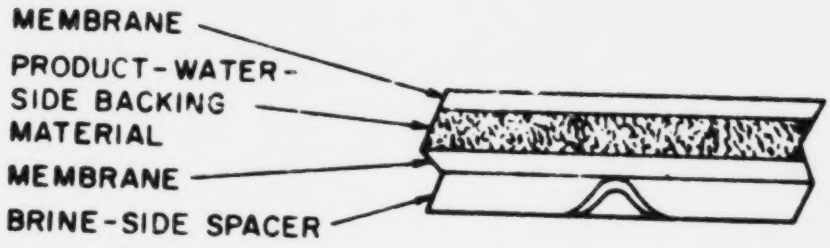


Figure 12. A Spiral-Wound Reverse Osmosis Module

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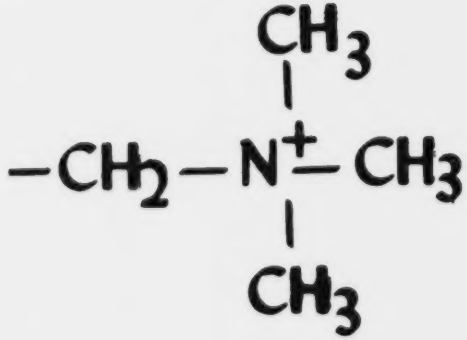
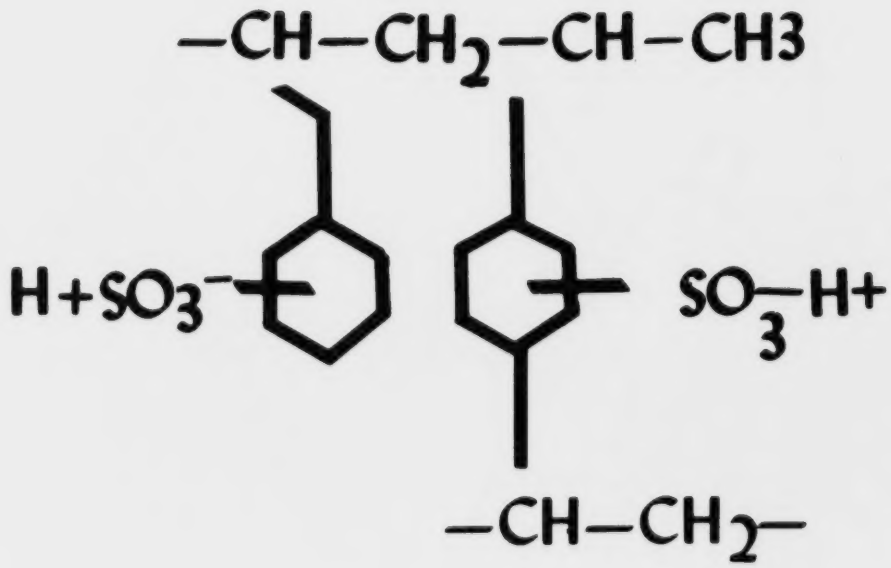


STRONG BASE RESIN



STRONG ACID RESIN

FIG. 13

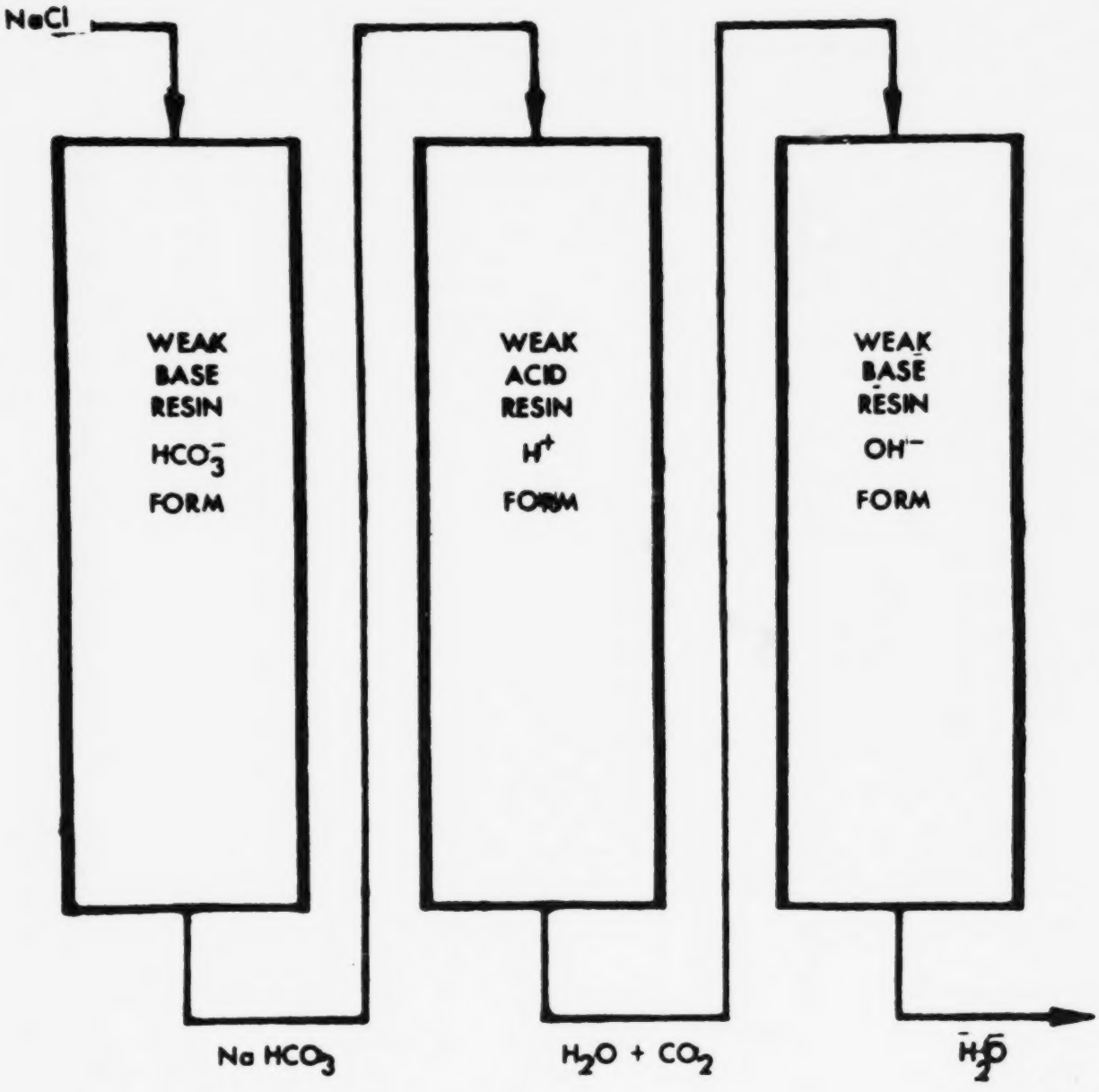


Figure 14. DESAL Process

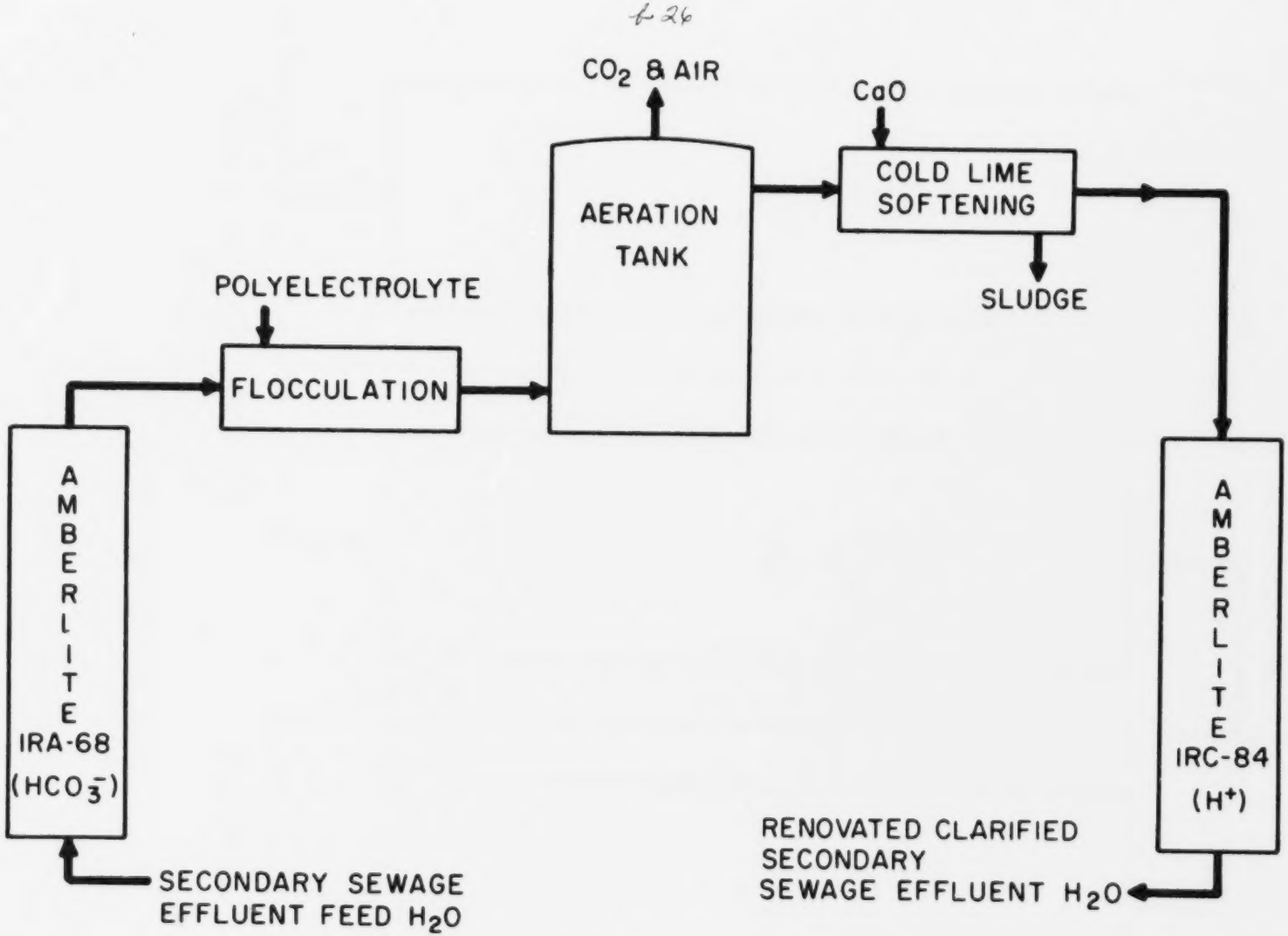


Figure 15. Flow diagram of ion exchange process for renovation of secondary sewage effluent

FIG. 16 **Cost Estimate for Renovation of Haddonfield, N. J., Secondary Sewage Effluent**

	$ Cost/1000 Gal.	
	1,000,000 gal./day	10,000,000 gal./day
Alkalization	0.0655	0.0631
Dealkalization	0.0500	0.0478
Carbonation	0.0030	0.0030
Degasification	0.0042	0.0029
Flocculation (chemicals only)	0.0436	0.0436
Lime softening	0.0158	0.0158
Grand total	$0.1821	$0.1762

#28

BACTERIAL AND VIRAL CONTROL AND WATER REUSE
(for domestic purposes)

by

Harold W. Wolf, Dr.P.H.*

Introduction

The problems that we face in any consideration of reusing treated wastewaters for domestic purposes, even if they be limited to the microbiological, are really quite demanding. The reason for this difficulty is basically one of philosophy but a philosophy that carries over to the technical area. It is not generally realized, but the U.S. Public Health Service Drinking Water Standards, upon which we must ultimately evaluate qualities of treated wastewaters, is, to a great extent a standard of expedience. It does not exclude entirely the possibility of acquiring an intestinal infection. It is attainable by the economic development of available water supplies, their disinfection, and if need be treatment in purification works by economically feasible methods. It is not a standard of perfection. Fair & Geyer[1] note that the application of the Standard to areas of high endemicity of diseases that are transmittible through drinking water is challengeable.

In any consideration of drinking treated wastewaters we cannot accomodate a philosophy of expedience. We must be dead certain that no one is going to become ill by virtue of drinking this type of water. This added degree of certainty is really what makes the microbiological problem so difficult. Disinfection is a rate process and it is a complicated rate process dependent upon the physico chemistry of the disinfectant, the cyto-chemical nature and physical state of the pathogens, the reaction of the two, and quantitative effects of factors in the reaction medium such as temperature, pH, electrolytes, and interfering substances. Coupling the absolute certainty of non-infectivity with the wide

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variation that occurs in the quality of wastewaters plus the even broader variations in numbers and types of pathogenic organisms, one must admit that the problems are, indeed, formidable.

Meeting Drinking Water Standards

We have all repeatedly seen references to articles proclaiming that sewage has been treated to such a high degree that it meets Drinking Water Standards. Such statements are not accurate. What is meant is that they meet some of the requirements of Drinking Water Standards. There are two paragraphs (the first two definitions, in fact) in the Drinking Water Standards that are very much a part of those Standards. The requirements of these paragraphs must be met in order to render the judgment that a specific product water "meets Drinking Water Standards". The first refers to "Adequate protection by natural means" which "involves one or more of the following processes of nature that produces water consistently meeting the requirements of these Standards: dilution, storage, sedimentation, sunlight, aeration, and the associated physical and biological processes which tend to accomplish natural purification in surface waters, the natural purification of water by infiltration through soil and percolation through underlying material and storage below the ground water table".

The second paragraph concerns "Adequate protection by treatment " which means "any one or any combination of the control processes of coagulation, sedimentation, absorption, filtration, disinfection, or other processes which produce a water consistently meeting the requirements of these Standards. This protection also includes processes which are appropriate to the source of supply; works which are of adequate capacity to meet maximum demands without creating health hazards, and which are located, designed and constructed to eliminate or prevent pollution; and conscientious operation by well-trained and competent personnel whose qualifications are commensurate with the responsibilities of the position and acceptable to the Reporting Agency and the Certifying Authority".

Since "adequate protection by treatment" has not been defined by the Public Health Service, which is the Certifying Authority referred to, there are no such waters that "meet Drinking Water Standards".

It has already been mentioned that Fair and Geyer state that the application of the coliform standard is questionable in areas of high endemicity of waterborne diseases. It can therefore be stated that the Standard is also similarly questionable if it is to apply to a source water when that source water is sewage.

Viruses

The Committee on Environmental Quality Management of the Sanitary Engineering Division of the American Society of Civil Engineers has recently published a paper "Engineering Evaluation of Virus Hazard in Water"[2]. The paper quotes the following analysis of the significance of low concentrations of viruses by Hillel Shuval of Israel:

"The findings of Dr. Lund, confirmed by the research in South Africa, that sewage treatment plants reduced the viral content of sewage by one or possibly by two logs, added to the estimate of Dr. Coin that one infectious dose of virus was present in 250 liters of Paris drinking water, provoke speculation. If the viral concentration in a sewage is 10 $TCID_{50}$ per ml and this amount is reduced as much as two logs in a sewage treatment plant, another three logs by dilution in a river, and two or three more logs in a water treatment plant, a total of seven or eight log reduction in viral concentration results. This leaves a water containing perhaps one $TCID_{50}$ of virus per 1000 liters. I suggest that this is not an unimportant amount. It is true that one person does not drink 1000 or even 250 liters of water per day, but one in 250 or one in 1000 or even one in 10,000 persons ingests one $TCID_{50}$ of virus daily and one $TCID_{50}$ is an infectious dose for man, as Dr. Plotkin suggested. Even after the viral concentration has been reduced 99.9999 percent, we have a level of ingestion of virus that could be responsible for a proportion of the endemic viral diseases in communities consuming highly treated waters."

It is therefore quite obvious that in any consideration of using highly treated wastewaters as a domestic supply, the treatment processes must be extremely efficient in destroying viruses.

Microbiological Control

The same A.S.C.E. publication then asks the question "Can (the) coliform index be reasonably applied to (an) evaluation of enteric viruses in water?" In response to this question, the committee quotes Clarke[3] extensively as follows:

"In order to answer this question, the following factors must be considered:

"1. The relative numbers of indicator bacteria and viruses in water and sewage must be known.

"2. The relative effectiveness of water and sewage treatment processes on bacteria and viruses must be determined.

"3. The relative survival time of the two groups of microorganisms must be evaluated.

"4. Is there epidemiological evidence that water which does or does not meet bacteriological standards can be responsible for infection and/or disease in humans?

"The relative numbers of coliform bacteria and viruses in water and sewage have been discussed by Clarke et al.[4] These authors have calculated that the average enteric virus density in domestic sewage is probably about 500 virus units per 100 ml .... coliform densities in domestic sewage average 46 x 10^6 per 100 ml... thus, coliform-virus ratios in sewage are about 92,000 to 1.... It is apparent that coliform organisms far outnumber enteric viruses in sewage... and therefore are a far better indicator of pollution than are enteric viruses.

"The next point to be considered is the relative effectiveness of water and sewage treatment processes in removing or destroying viruses and bacteria in water or sewage. Kabler et al.[5] summarized the viricidal efficiency of a number of water disinfectants. They concluded that different types of enteric viruses vary widely in their resistance to chlorine and that at least some types of polio-

virus, Coxsackie viruses, or E.C.H.O. viruses are more resistant to chlorine than are coliform or enteric pathogenic bacteria. Although some of these viruses are markedly more resistant to chlorine than are coliform bacteria, Clarke and Chang[6] concluded that any enteric virus so far examined would be effectively destroyed by a free chlorine residual of about 1.0 ppm, provided it could be maintained for about 30 minutes and the virus particles were not embedded in particulate material....

"There is no doubt...that water can be adequately treated so that it is always biologically safe. Adequate treatment means good clarification...followed by effective disinfection which can be carried out only with water free from suspended material. This has been pointed up very clearly by Sanderson and Kelly[7], who cite a case in which coliform bacteria were constantly isolated from waters containing between 0.1 and 0.5 mg/l of free residual chlorine and between 0.7 and 1.0 mg/l of total residual chlorine after 30 minutes contact time. They also point out that data on the effectiveness of chlorine disinfection as determined by laboratory studies conducted under favorable conditions are not applicable to turbid waters. The chlorinated water in which they consistently found coliform organisms had turbidities ranging from 3.8 to 8.4 units, had iron rust, and had biological organisms of 2000 units on occasion. Viruses, being much smaller than bacteria, would appear to have more opportunity to become enmeshed in a protective coating of turbidity-contributing materials and thus more opportunity to escape disinfecting action. It is therefore advisable that turbidities in final effluents be kept well below one Jackson unit. In fact, for most effective chlorination it would be well to have the turbidity as low as 0.1 unit as recommended by A.W.W.A. water quality goals. (Incidentally, it should be understood that the limit of 5 Jackson Units of turbidity specified in the Public Health Service Drinking Water Standards of 1962 is meant to apply to protected watersheds and not to effluents from filtration plants.) With turbidities as low as 0.1 to 1, a pre-plant chlorine feed need be only enough to have a 1 mg/l free chlorine residual after a contact time of 30 minutes. Post chlorination practice would depend upon the ability to maintain such residuals throughout the distribution system."

The A.S.C.E. Committee then goes into the following conclusion:

"There is no doubt that a positive coliform index means that virus may be present. Absence of coliform, however, may not mean that virus is absent. The coliform index, therefore, while a good laboratory tool is not a reliable index for viruses. Greater assurance of the absence of virus would be a turbidity of less than 0.1 Jackson Unit and an HOCl residual of one ppm after a contact period of 30 minutes. While freedom of virus hazard may be associated with the latter conditions, it would be desirable that a viral index be utilized to supplement the coliform index. Virologists engaged in water supply research should consider this need."

We have a good laboratory tool for the determination of chlorine residuals in the amperometric titrimeters. We lack a good tool for the measurement of turbidities in the range of 0.01 to 1.0 Jackson Units. If such a reliable instrument were made available it would be possible to commence studies on the control of infectious bacteria and viruses by relating them to the chlorine residuals and turbidities.

Conclusions

The very first Drinking Water Standard Committee added the following concluding comment to their very important work. "It is requested that the recommendation of these hard-and-fast limits of bacteriological impurity be not interpreted as minimizing in any way the importance of field surveys in estimating the sanitary quality of water supplies in general. It is always desirable to obtain information from as many angles as possible, and this is, indeed necessary in order to form an altogether fair estimate of an individual supply." This is precisely the same situation we are in with respect to the domestic reuse of wastewaters, viz., "It is...desirable to obtain information from as many angles as possible..."

While studies of bacteria and virus pathogen control should be directed to HOCl residuals, time, and turbidity, we will for a long time have to couple these analyses to viral assays, coliform count, and, indeed, include other possible microbiological problems,

perhaps using a total count procedure and/or specific quantitating techniques for such organisms as pseudomonads which have been reported in many instances to be problems with several tertiary treatment devices.

In 1919, a Public Health Service medical officer stated[8]: "Water supplies heretofore have been passed upon by bacteriological standards. Very little attention has been paid to (sanitary) survey standards which engineers would likely set. I think the time has come to adopt the engineering point of view. The bacteriologist will only be a checker-up and I think I can convince you... that we should adopt the (sanitary) survey method of accepting a water supply rather than the bacteriological."

I submit that this is a big world with plenty of room for engineers, bacteriologists, virologists, chemists, and medical doctors. Certainly it will take an abundance of teamwork involving all disciplines to achieve bacteria and viral control in water reuse. The Public Health Service and the Committee on Environmental Quality Management of the Sanitary Engineering Division, A.S.C.E. have clearly pointed the way.

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THE CONCEPT OF

WASTEWATER RECLAMATION

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For presentation at the 44th Annual Meeting of the Rocky Mountain Sections of AWWA – WPCA – September 1970.

INTRODUCTION

The concept of wastewater reclamation is neither new nor unique. Even in Biblical times it was known. Ecclesiastics, Chapter 1, Verse 7, states: "All the rivers run to the sea, yet the sea is not full. Unto the place from whence the rivers came, thither they return again."

Like any "new" concept, water reclamation has its friends and its foes. Both sides have many arguments supporting their positions. By way of a comparison, detractors of the Wright brothers said of man's early attempts to fly, "If God intended that man should fly, He'd have given us wings"! In answer to similar hysteria over the reuse of wastewater, we could as easily retort, "If God had meant us to use only new water, He'd either have given us more of it or created far fewer of us".

The purposes of this paper are twofold: to advance some of the many logical arguments in favor of wastewater reuse; and to cite some actual case histories of wastewater reuse operations as a means of showing what has already been accomplished.

ALTERNATIVE CONCEPTS

There is at least one alternative approach to most concepts. If we consider the reclamation concept as one possibility, its antithesis might be termed the wastewater concept. These two concepts are briefly defined below.

1. THE RECLAMATION CONCEPT

Water, once used for domestic and industrial purposes, still constitutes a natural resource that can be renovated and reused. To be justified, the reuse must be shown to be beneficial, economically feasible, and above all safe public health practice. Benefits accruable to reclamation and reuse include the identifiable economic, ecological and social impact on receiving waterways because of greatly reduced pollutional loads. These benefits are to some extent intangible since a dollar value or "price tag" for elimination of pollution is difficult to calculate. In addition, other benefits, including reduced costs for development of alternate sources of potable water supply, maximum development and use of the existing water resource, the ability to serve more people and industries and the increase of the tax base, must be considered. Failure to recognize both tangible and intangible benefits of water pollution abatement will generally result in making economic justification of water reclamation and reuse impossible

2. THE WASTEWATER CONCEPT

This approach implies continued acceptance of the premise that sewage is merely wastewater, something fit only to be discarded. This concept would logically lead to the conclusion that the pollution problem can be solved by much the same methods presently used; i. e., removal of as much of the pollutants contained in wastewater as is necessary to meet disposal requirements. Certain modifications in treatment and disposal techniques would have to be developed and implemented as pollution abatement standards become more strict, but the main idea would be to dispose of the water as a waste product, as simply as possible, consistent with the needs of the ecology of the receiving waters. Benefits accruable to this concept include the intangible aspects of pollution abatement, as in the water reclamation concept (although often to a lesser extent, depending on the purity of the effluent). Other benefits might be possibly lower costs for wastewater treatment facilities, increased stream flow for downstream users and ready public acceptance. However, the wastewater concept also has what might be termed "negative benefits," and these must be included in any logical overall comparison. These "negative benefits" are costs of developing alternate sources of potable water supply to replace effluent wasted downstream, and the possibility of placing a limit on area growth by virtue of a finite limit on available new water. Failure to recognize these and possibly other "negative benefits" may in fact constitute the major justification (and a false one) for continued waste of treated sewage effluents, at least in areas where water is a critical factor.

BENEFITS OF WASTEWATER RECLAMATION

1. POLLUTION ABATEMENT

One of the major benefits of any wastewater reclamation program is the removal of pollutants from wastewater to a degree greater than that obtainable from conventional secondary waste treatment processes. Generally, the quality standards required to make water reuse practical are such that advanced waste treatment is necessary to reduce oxygen demand; to reduce the nutrient content; to avoid undesirable algal growths; to remove final traces of suspended solids; to remove color, taste and odor; and, finally, to remove refractory materials.

Removal of pollutants causing oxygen demand is generally measured either in terms of BOD or COD removal. Items which contribute to BOD or COD in wastewaters cause a depletion of dissolved oxygen content within receiving waters. Consequently, unless the receiving water has a sufficient capacity to assimilate the oxygen demand of the incoming wastes, dissolved oxygen levels fall below desirable levels, with attendant loss of desirable aquatic fauna.

Nitrogen and phosphorus are the primary algal nutrients. Wastewaters rich in phosphorus and nitrogen stimulate the growth of algae. In clean reservoirs and streams, a delicate balance is maintained between the growth of algae and the growth of other aquatic flora and fauna. In water which receives an over-abundance of nitrogen and phosphorus, the usual result is the stimulation of greatly increased algal activity with attendant "blooms" of these minute plants. A stream or reservoir which suffers from a continuing over-abundance of nitrogen and phosphorus inevitably is on the road to degradation and eventual death as a usable body of water. This process of enrichment, because of nutrients, is termed eutrophication. Eutrophication is a naturally occurring process; eventually, the fate of most streams and lakes would be conversion first to swamps, and eventually, meadows, even without the enrichment provided by the activities of man. The rate at which eutrophication occurs is unfortunately tremendously stimulated by the activities of man, primarily because of wastewater discharges, but also to a significant degree because of the use of agricultural fertilizers on crop lands, lawns and gardens.

Suspended solids carried in wastewater effluents tend to settle in quiescent pools, in reservoirs, or receiving streams, forming sludge deposits on the bottom. These deposits are commonly known as benthol deposits and have at least two major detrimental effects. If the benthol deposits remain on the bottom, they are subject to decomposition. If this decomposition takes place in the presence of oxygen, it represents an oxygen demand. If the decomposition takes place in the absence of oxygen, malodorous conditions result. Even if suspended solids did not settle to the bottom, they represent an undesirable condition by causing increased turbidity, which decreases the aesthetic appeal of a receiving water. In addition, if present in large quantities, suspended solids have an adverse effect upon aquatic life, especially the more desirable fish species such as salmon and trout.

The presence of materials which cause color, taste or odor in receiving water probably needs little discussion since these materials are readily ascertainable to anyone who takes the trouble to use his senses.

Refractory substances, in general, may be defined as those substances which contribute to the total organic carbon content of water, but do not generally represent either a BOD or COD demand. In particular, these include synthetic detergents and many of the organic pesticides which may find their way into waters. These substances can definitely be linked to such diseases as cancer in humans and, even if not carcinogenic, may cause undesirable side effects such as foaming or frothing of receiving waterways.

2. SUPPLEMENTING THE AVAILABLE WATER RESOURCE

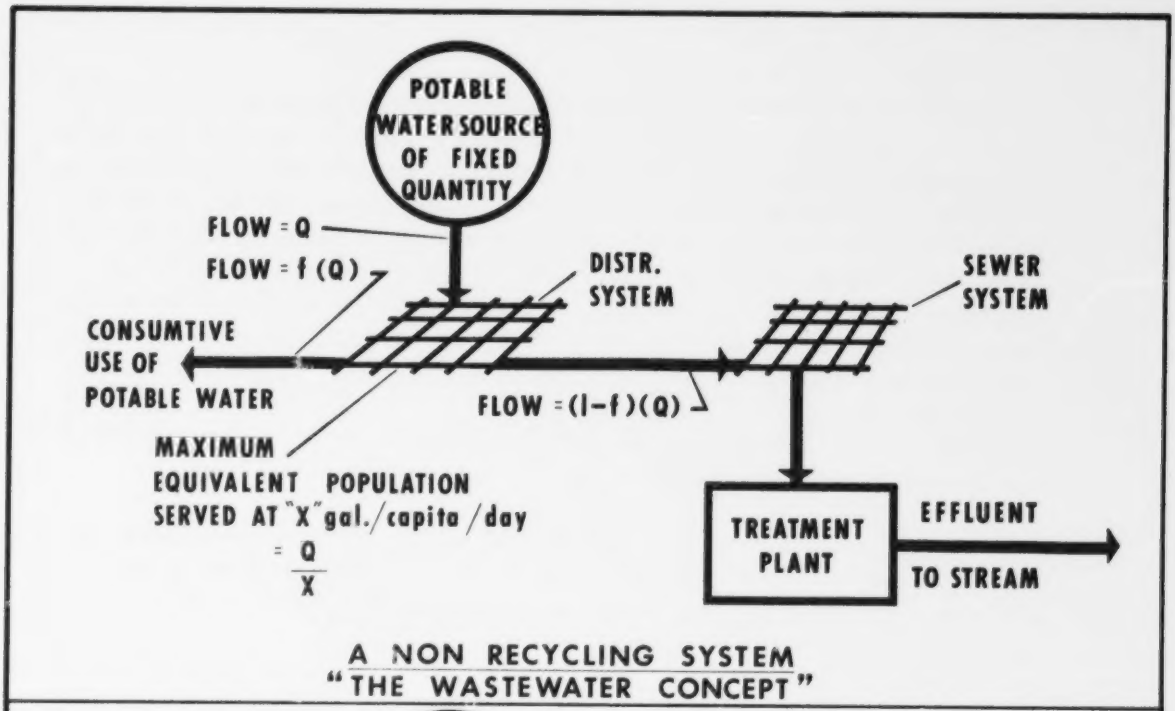
Another major benefit of water reclamation and reuse is the supplementing or enlargement of what may otherwise be a fixed quantity of water available for use to a given area. In many areas of the U. S., the quantity of water available from either surface or subsurface sources is limited; such a limit in turn imposes a limit on the total number of people and/or the total amount of industry which can be supported in a given area. Water reclamation and reuse can multiply the apparent supply by recycling reclaimed water without the necessity of developing new sources of water. Figure 1 illustrates this concept graphically.

In conjunction with water reclamation and reuse, the quality of water required for various uses often dictates the most desirable form of reclamation and reuse. For example, water for most agricultural uses and many industrial uses need not be of as high a quality as that used for human consumption. In such cases, water reclamation may take the form of irrigation of crops and use of treated effluents for industrial purposes. The net result is that the potable water supply source and system can be relieved of the burden of supplying these needs. In areas which depend largely on groundwater sources, artificial recharge of the groundwater resource either by injection or spreading of reclaimed water is often possible. This also results in augmenting the available source by essentially "banking" reclaimed water in the subsurface against the time when withdrawal of groundwater exceeds the natural recharge.

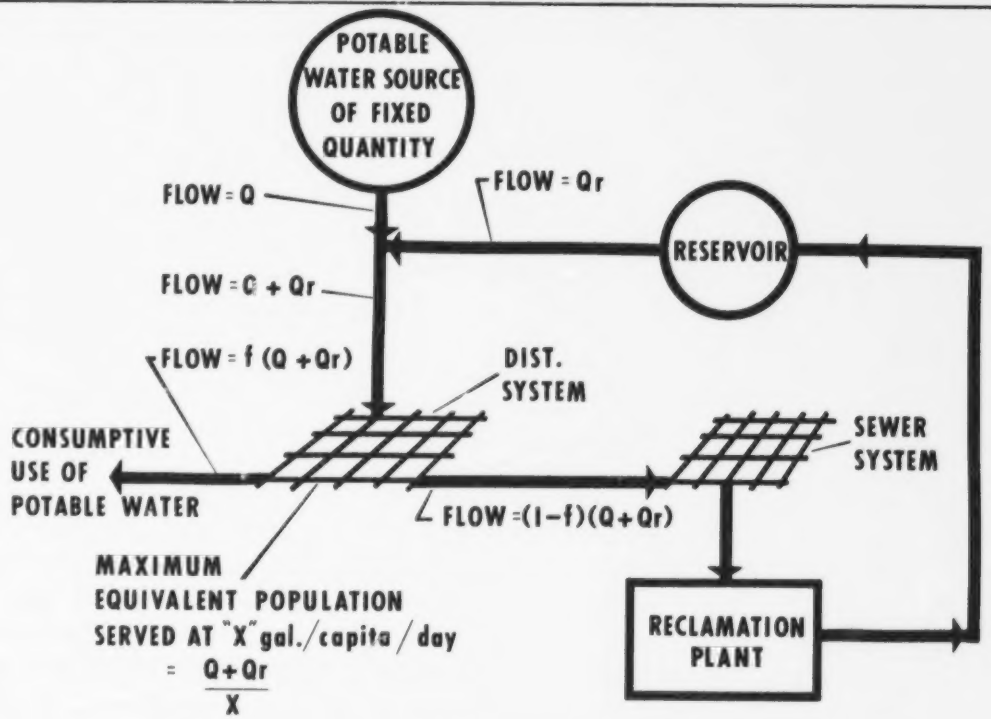
Finally, in areas where sufficient potable water is not available, highly purified reclaimed water can be recycled into the potable water system, thus increasing the overall quantity of potable water available. Such action certainly should not be implemented without considerable study and research covering all possible effects. It is not, however, an action without precedent; direct domestic recycling is now being practiced in some areas of the world and will undoubtedly become more widespread in the future. A case history involving such a direct potable water recycle is dicussed later in this paper.

3. ECONOMIC ADVANTAGES

The final major benefits of water reclamation and reuse may very well prove to be economic in nature. For example, the State of Nevada recently adopted water quality standards for the Las Vegas area which are so stringent that, if met, treated wastewater would be purer in nearly all respects than the waters of Lake Mead. However, Lake Mead, after the completion of the Southern Nevada water project, will constitute the major source of potable water for the Las Vegas area. Under the present Nevada water quality standards, desalinization of wastewater before discharge into Lake Mead would be



A NON RECYCLING SYSTEM
"THE WASTEWATER CONCEPT"



A RECYCLING SYSTEM
"THE RECLAMATION CONCEPT"

FIGURE 1
GRAPHIC COMPARISON OF THE WASTEWATER AND RECLAMATION CONCEPTS

CH2M

required. It would therefore be far superior in many characteristics to natural Lake Mead water. Hence, unless the wastewater were to be reused it would, at least in some respects, be polluted by admixture with Lake Mead water. Thus, the very high cost of treatment would be lost for the most part, since the relative volumes are such that Lake Mead itself would be but little improved. On the other hand, reclamation and reuse plans currently under study include the use of some of the wastewater for cooling thermal power generation facilities and, in conjunction with such generation facilities, recovery and desalinization of some of the wastewater by multiple effect distillation. The desalinized reclaimed water would then be fed directly into the potable water system, actually improving the quality of the supply from the standpoint of dissolved solids content. At this point in time, the estimated net costs involved appear to be less than the cost of merely treating wastewater for disposal.

In other areas where treatment requirements may not be as restrictive, savings may still be realized by planned water reclamation. Certainly a portion of water use in nearly any sizable community may be satisfied with less than drinking water quality. The City of Colorado Springs provides such an example. For a number of years the City has maintained a nonpotable water system to supply irrigation water. This system has utilized both untreated surface water and sewage effluent that has passed through secondary treatment. Recently, the City began construction of a tertiary treatment system to augment their nonpotable water supply system. Their tertiary treatment plant will provide additional treatment for about 12 mgd of secondary effluent and produce two qualities of nonpotable water: a high grade water for cooling thermal power generation and a water of lower quality for irrigation. The system will, in addition, significantly reduce the amount of pollution entering Fountain Creek, which is the receiving stream for the effluent. Even without considering any costs for possible development of other sources of water to meet increasing demands, Colorado Springs found water reclamation to be economically justifiable. Certainly if the costs of new source development and the intangible benefits of pollution abatement were to be added, water reclamation at Colorado Springs would be even more economically favorable.

A BRIEF HISTORY OF WASTEWATER RECLAMATION

1. THE CHANUTE STORY

The City of Chanute is a relatively small community in southeastern Kansas. Its sole source of water supply is the Neosho River. Chanute maintains and operates a conventional rapid sand filtration plant to provide treatment for Neosho River water prior to introduction into the City's potable water distribution system. During the years 1953 through 1957, a record drought struck the tributary area of the Neosho; and as a

result, flow in the river became progressively smaller until in early 1956 it practically ceased. Although all possible water conservation measures and limited flow augmentation procedures were pressed into use at Chanute, the water supply continued to dwindle. The situation became progressively worse until on October 14, 1956, without fanfare of any sort, City officials opened a valve which permitted mixing of sewage effluent which had received conventional secondary treatment, with water stored in the Neosho River channel behind the water treatment plant impoundment dam. During the period of water reuse, the waste treatment removed, on the average, 86 percent of the BOD and 76 percent of the COD content of the wastewater. It substantially reduced both total and ammonia nitrogen concentrations; detergent concentrations decreased an average of 25 percent. The recycling process was employed for a total of five months during the fall and winter of 1956 and 1957. It was estimated that one complete cycle through the waste treatment and back through the water treatment required about 20 days. Thus, during the total period of time during which water recycling was practiced, the same water passed through the treatment plant approximately seven times.

The treated water discharged from the water treatment plant had a pale yellow color and an unpleasant musty taste and odor. It foamed when agitated and contained undesirable quantities of minerals and inorganic substances. However, there were no known cases of water-borne disease or other adverse effects upon health resulting from the use of the recirculated water supply.

As a young sanitary engineer with the Kansas State Board of Health at the time, I vididly remember, in particular, one of the humorous anecdotes that arose from this episode. The comment was made that the water at Chanute "finally got so damn strong that we shut off the high service pumps and it pushed itself through the mains."

2. THE WINDHOEK STORY

Since the Chanute episode in 1956, the technology of wastewater treatment has indeed come a long way as represented by the latest example of reclaiming waste for domestic water supply at Windhoek in Africa.

Near the end of 1968, Windhoek, the capital of South-West Africa, became the first city in the world to practice large-scale and continuous reclamation of wastewater effluent for drinking purposes. Its wastewater reclamation plant has a design capacity of 1.2 million imperial gallons per day. Treated wastewaters constitute approximately one-third of the City's total water supply.

Prior to installation of the reclamation plant, Windhoek's main sources of water supply were a number of wells and a surface water supply from a nearby impoundment. In order to maintain the City's rate of development, augmentation of these sources of supply became necessary. The City of Windhoek is situated in a very arid region and surface water resources are scarce and expensive to develop because they involve the pumping of water over long distances. Under these circumstances, reclamation offered the cheapest solution to the problem.

The reclamation process involves the following unit process use: flocculation-flotation, detergent removal by foam fractionation, lime treatment, sterilization by chlorination, settlement of calcium carbonate sludge, sand filtration, filtration through activated carbon, and final rechlorination.

The quality of the reclaimed water easily complies with World Health Organization standards for drinking water. Excessive build-up of total dissolved solids is limited by the high natural consumptive water use in the area so that desalting is unnecessary.

No public opposition to the final scheme has become apparent.

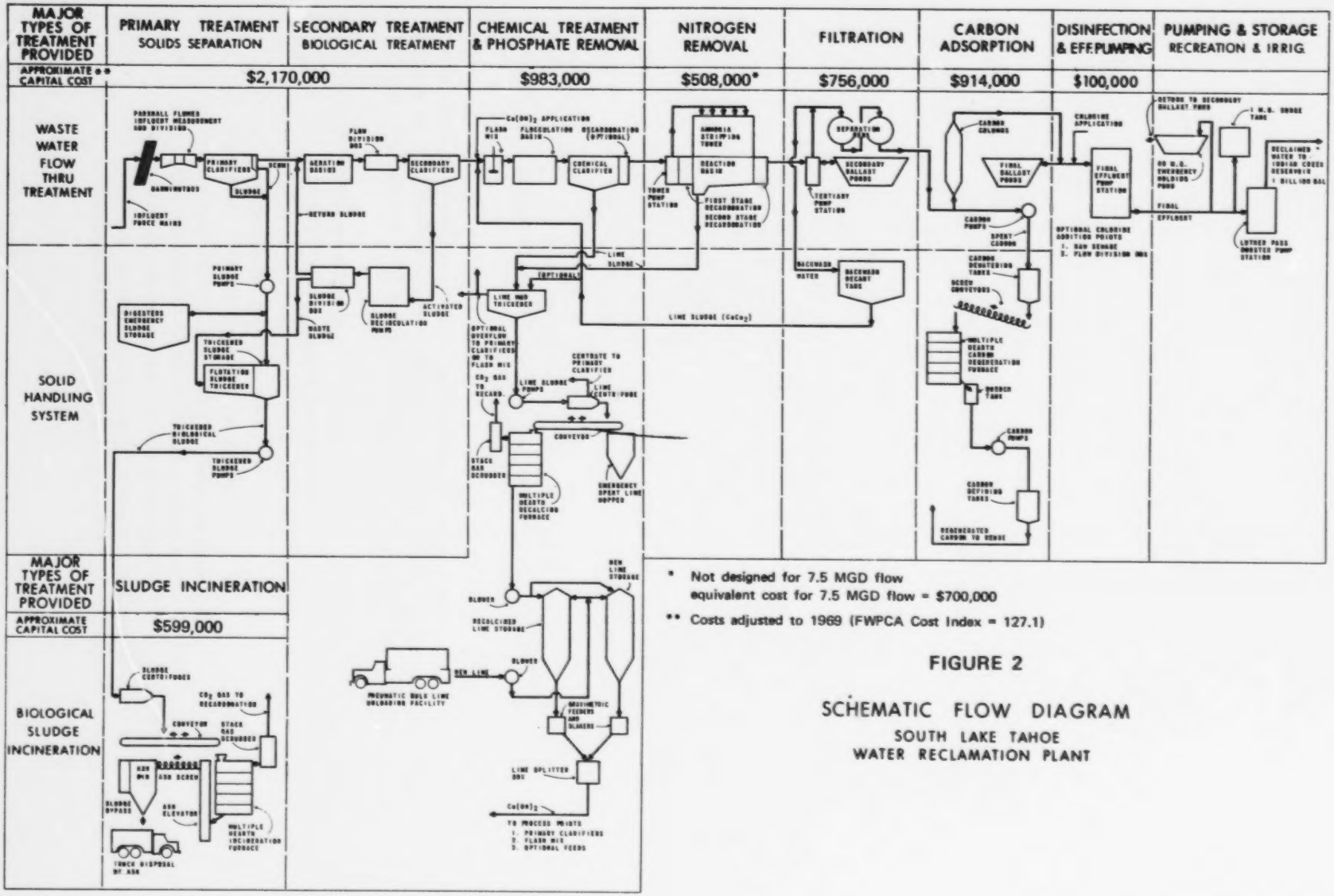
The Windhoek plant was officially opened on January 21, 1969, by the South African Prime Minister, Mr. Vorster. The prime minister stated in his formal address that, ". . . in the future it might prove more advantageous to subsidize local authorities to reclaim their effluents than to build new reservoirs which would involve the piping of water over long distances."

3. THE TAHOE STORY

There are only about five full-scale advanced wastewater treatment plants in the U. S. that are capable of producing the high degree of treatment required for domestic recycling of reclaimed wastewater. Perhaps the most notable of these, and certainly the first to go into full-scale operation, is the South Tahoe Public Utility District water reclamation plant at South Lake Tahoe, California.

Since March 31, 1968, the South Tahoe plant has operated without shutdown, 24 hours a day, and has continuously produced an effluent quality exceeding all the stringent requirements of regulatory agencies exercising jurisdiction in the area. At the present time, it is probably the only such facility in the U. S. which has for nearly three years produced an effluent capable of meeting drinking water standards.

Figure 2 is a simplified, schematic flow diagram of the process employed at STPUD to provide the high degree of purification and nutrient removals required. The process consists of 10 major component systems as follows:



* Not designed for 7.5 MGD flow
equivalent cost for 7.5 MGD flow = $700,000

** Costs adjusted to 1969 (FWPCA Cost Index = 127.1)

FIGURE 2

SCHEMATIC FLOW DIAGRAM
SOUTH LAKE TAHOE
WATER RECLAMATION PLANT

1. Conventional Primary Treatment
2. Completely Mixed Activated Sludge Secondary Treatment
3. Chemical Coagulation and Sorption with Lime
4. Nitrogen Removal by Air Stripping of Ammonia
5. Filtration Through Mixed Media Separation Beds
6. Granular Activated Carbon Adsorption
7. Disinfection by Chlorination
8. Coagulant Recovery by Recalcination
9. Thermal Activated Carbon Regeneration
10. Sludge Incineration

The continuously high degree of pollutant removal from the reclaimed water achieved by the Tahoe Process is shown by the data in Table 1, which gives the average overall efficiency since commencement of operations in March 1968.

TABLE 1
REMOVAL EFFICIENCY FOR THE SOUTH TAHOE
PUD WATER RECLAMATION PLANT

Parameter	Percent Removal
BOD	99.4
COD	96.4
MBAS	97.9
Phosphorus	99.1
Suspended Solids	100
Color	100
Odor	100
Turbidity	99.9
Coliform Bacteria	100
Virus	100

While the efficiency of removal of pollutants shown in Table 1 is indeed impressive, it is perhaps of greater significance to compare the average quality of reclaimed water from the Tahoe Process to various recommended drinking water standards. This comparison is made in Table 2.

TABLE 2
COMPARISON OF RECLAIMED WATER FROM THE
TAHOE PROCESS AND THE RECOMMENDED AWWA GOALS
FOR POTABLE WATER

Parameter		Recommended AWWA Goals for Potable Water	Reclaimed Water from STPUD Plant	Remarks
MBAS	mg/l	0.2	0.2	Meets Standard
Cl^-	mg/l††	250	28	Meets Standard
SO_4^-	mg/l††	250	36	Meets Standard
Color	units	3	0	Meets Standard
Odor	ton	None	None	Meets Standard
TDS††	mg/l	500	300	Meets Standard
COD†	mg/l	10	11	Exceeds Standard by 1 mg/l
BOD†	mg/l	6	1.5	Meets Standard
NO_3	mg/l as N	10	0.2	Meets Standard
S. S.	mg/l	1.0	0	Meets Standard
Turb.	mg/l	0.1	0.3	Better than most U.S. water supplies
Coliform	MNP	None	None	Meets Standard
Hardness	mg/l as $CaCO_3$	80	150	
PO_4^-	mg/l as P	No Standard	0.1	

†† USPHS Drinking Water Standard – Not AWWA Goal.
† World Health Organization Standard – Not AWWA Goal.

Reclaimed water from the Tahoe system is not reused for domestic supply purposes. Rather, in conformance with state law, it is exported out of the Tahoe basin. However, beneficial use is made of the reclaimed water. All effluent is impounded in a new man-made reservoir located some 30 miles from the treatment plant in Alpine County, California. The reservoir has a capacity of about 3,000 acre-feet, and since its initial filling has consistently maintained a very pleasing appearance. It has been approved by local and state regulatory agencies for all water contact sports. The reservoir supports a thriving population of rainbow trout and a state grant has been awarded for construction

of additional recreation facilities. Its water is sparkling clean and Secchi disc observations have been recorded as high as 20 feet. The low level of phosphorus in the water, coupled with the very low organic carbon content, appears to control algal growth adequately. During the irrigation season, a portion of the water in the reservoir is released for irrigation of forage crops by downstream ranchers in the area.

4. THE DENVER SUCCESSIVE REUSE PROGRAM

The Denver Board of Water Commissioners has long been recognized as one of the most progressive bodies in the water utility field. Their past engineering achievements in supplying high quality water to the City and County of Denver include some of the most difficult projects ever constructed. For example, the H. D. Roberts tunnel, completed in 1962, is the world's largest major underground tunnel (23.2 miles). The tunnel bore is as deep as 4,465 feet below the earth's surface and provides transmountain diversion of Blue River water to the Denver system.

With what must be termed typical foresight, the Denver Water Board has recognized that the time is approaching when even such enormous projects as transmountain diversion of west slope water will not assure totally adequate reserves of fresh water for Denver. They have therefore embarked on a research and development program to investigate and design reclamation systems to reuse wastewater. Initial plans call for a 10 mgd industrial reuse system. The Board proposes to expand the reclamation system to an ultimate capacity of 100 mgd of wastewater, with a large portion being recycled into domestic use. This project represents the largest reuse plan yet undertaken anywhere in the world and certainly is in keeping with the past achievements of the Denver Water Board.

5. OTHER RECLAMATION EXAMPLES

The foregoing examples are but a few of the many operational or projected reclamation systems. Another example of direct domestic reuse will soon be operational in South Africa with a one mgd potable water reuse plant now in experimental operation at Daspoort, Pretoria, South Africa. The Daspoort plant is very similar to the Tahoe system, using lime coagulation, ammonia stripping, and activated carbon filtration. In our own country, no listing of reclamation projects would be complete without mention of the Santee, California, project which provides reclaimed water for recreational uses. Other examples include Hyperion, California, and Long Island, New York, where reclaimed water is injected into subsurface formations to provide a salt water barrier. Finally, numerous examples of advanced wastewater treatment for pollution abatement are now under construction in the U. S. These include plants at Blue Plains (Washington, D. C.), Rocky River, Pennsylvania, and Chicago, Illinois.

PROBLEMS ASSOCIATED WITH WASTEWATER REUSE

There are still problems to overcome before wastewater reclamation, at least for domestic reuse, can become an everyday occurrence. First, the reliability of treatment processes must be improved, and along with this, the rapidity with which analysis of various pollutants can be made must be increased. Until these improvements are possible, it will probably be necessary to impound reclaimed water in reservoirs prior to release to raw water intakes at potable water treatment plants.

Bacteriological and virological testing techniques also need improvement. Today, our techniques are extremely limited. Even though extensive virological testing at both Tahoe and Windhoek have indicated no passage of viable virus through the treatment system, we are not certain that no such passage occurs, because of the difficulty of culturing any but a very few of the known viral organisims.

The progressive build-up of dissolved solids is another potential problem in water reclamation. Fortunately, this is a problem which can be solved by current technology, albeit at considerable cost, by such techniques as distillation, ion exchange, reverse osmosis and dialysis. Also, fortunately, the build-up of dissolved solids in most cases is not great due to the natural "blow-down" of dissolved solids from conventional U. S. water systems because of our prevailing rather high consumptive water use practices. The equilibrium concentration of dissolved solids that can be anticipated in any given recycling water system can be rather easily computed for any given moment if proper records are available. Figure 3 shows the general formulations necessary to solve such a problem. The technique shown was developed for computer solution with an IBM 1130 system, but it is adaptable to any computer system, or even hard calculations for that matter.

An interesting example may be obtained by using average figures for Denver (1968 data).

DATA

1968 average monthly potable water produced – 150 mgd
1968 average monthly TDS content of potable water – 135 mg/l
1968 average monthly TDS content of wastewater – 480 mg/l

ASSUMPTIONS

1. Assume 90 mgd reclaimed water recycled to domestic raw water supply.
2. Assume 50% of total flow consumptively used.
3. Assume 10% of reclaimed water consumptively used by irrigation and/or industry.

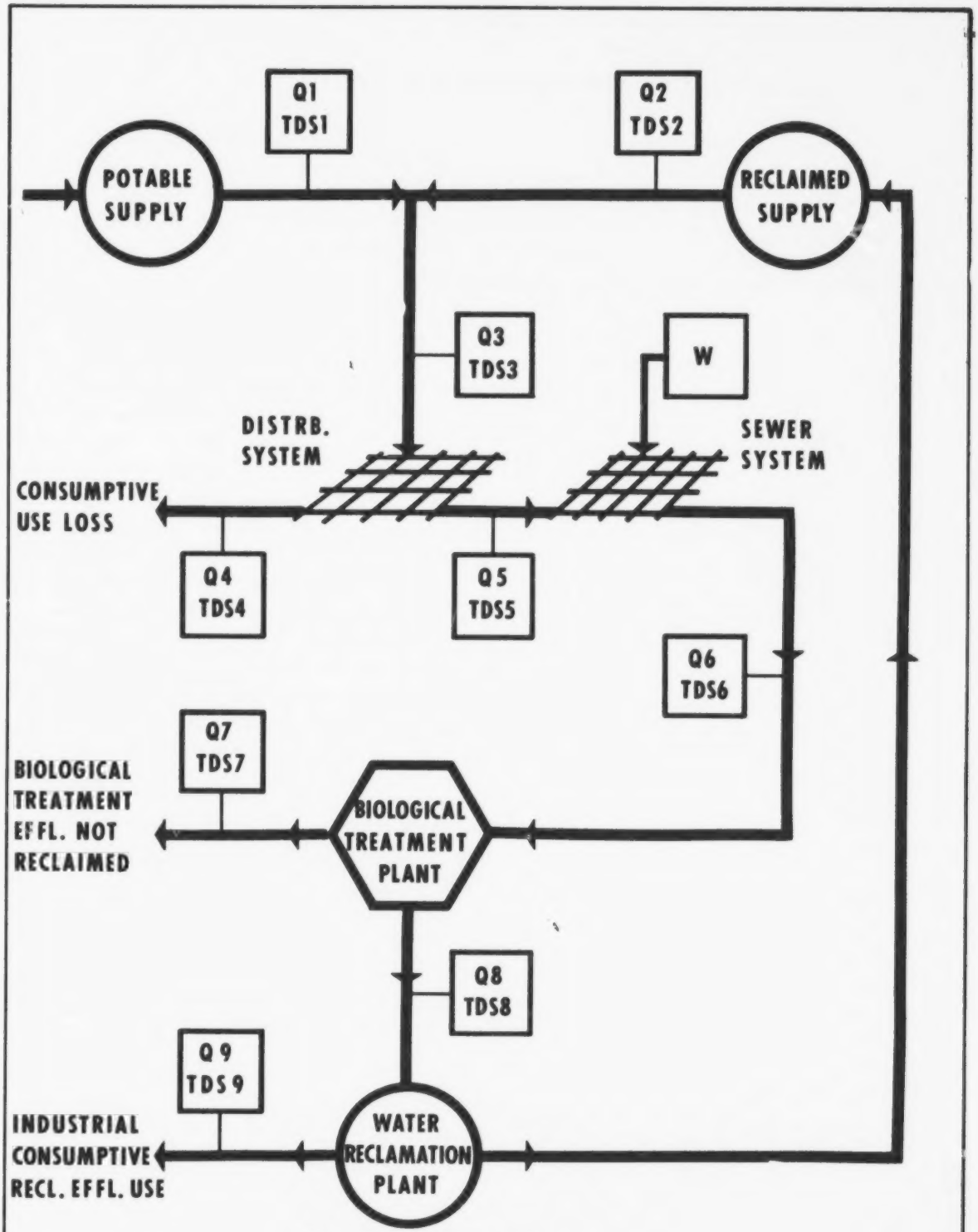


FIGURE 3

SCHEMATIC DIAGRAM OF A RECYCLING WATER SYSTEM

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NOMENCLATURE (For Figure 3)

Q1	= Flow into system from potable water supply	mgd
Q2	= Flow recycled into system from water reclamation	mgd
Q3	= Total flow to distribution system	mgd
Q4	= Consumptive water use in distribution system	mgd
Q5	= Flow to sewer system from distribution system	mgd
Q6	= Q5 = flow to biological treatment plant	mgd
Q7	= Flow from biological treatment plant not reclaimed	mgd
Q8	= Flow from biological treatment plant to reclamation	mgd
Q9	= Flow from reclamation plant to consumptive industrial use	mgd
TDS1	= Dissolved solids concentration of Q1	mg/l
TDS2	= Dissolved solids concentration of Q2	mg/l
TDS3	= Dissolved solids concentration of Q3	mg/l
TDS4	= TDS3 = Dissolved solids concentration of Q4 or Q3	mg/l
TDS5	= TDS3 = TDS4 = Dissolved solids concentration of Q3 or Q4 or Q5	mg/l
TDS6	= Dissolved solids concentration of Q6	mg/l
TDS7	= TDS6 = Dissolved solids concentration of Q6 or Q7	mg/l
TDS8	= TDS6 = TDS7 = Dissolved solids concentration of Q6 or Q7 or Q8	mg/l
TDS9	= TDS6 = TDS7 = TDS8 = Dissolved solids concentration of Q6 or Q7 or Q8 or Q9	mg/l
W	= Increase in TDS due to passage through sewer system	mg/l
X	= Decimal fraction of Q3 consumptively used	
Y	= Decimal fraction of Q6 not reclaimed	
Z	= Decimal fraction of Q8 not recycled	

EQUATIONS

Q1 = Given

TDS1 = Given

Q2 = Given

$Q3 = Q1 + Q2$

$$TDS2 = W + \frac{(Q1 \times TDS1 + Q2 \times TDS2)}{(Q1 + Q2)}$$

$$TDS3 = \frac{(Q1 \times TDS1 + Q2 \times TDS2)}{(Q1 + Q2)}$$

X = Given

$Q4 = X(Q1 + Q2)$

TDS4 = TDS3

TDS5 = TDS3

$Q5 = (1 - X)(Q1 + Q2)$

Q6 = Q5

TDS6 = TDS2

W = Given

$Q7 = Y(1 - X)(Q1 + Q2)$

$$Y = \frac{Q7}{(1 - X)(Q1 + Q2)}$$

TDS7 = TDS2

$Q8 = (1 - X)(1 - Y)(Q1 + Q2)$

TDS8 = TDS2

Z = Given

$Q9 = Z(1 - X)(1 - Y)(Q1 + Q2)$

TDS9 = TDS2

By using the formulations shown on Figure 3, and solving the problem for the equilibrium concentration of TDS in the blended domestic water supply, we find that such a practice would result in an increase in TDS to the consumer of 207 mg/l. Stated in other terms, drinking water at the homeowners tap would have increased from a TDS content of 135 mg/l to 342 mg/l. It would not rise above the value of 342 mg/l unless the relative volumes of 90 mgd reclaimed water to 150 mgd of "virgin" water were changed. It is doubtful if the consumer could detect such a change in TDS content, and furthermore the final TDS concentration would still be well below the USPHS allowance of 500 mg/l TDS.

Finally, we must be cognizant of public reaction to water reuse. The general public will not welcome the idea of drinking their own wastes. Experience has shown that the only way to overcome this rather natural reaction is by means of public education. The establishment of recreational reservoirs such as Indian Creek at the Tahoe project and the Santee Lakes at the Santee project have help the cause immeasurably. Such reservoirs may well be a vital key to public acceptance of wastewater reclamation; they may also be required unless or until better testing techniques are available to insure an absolute guarantee of safety for domestic reuse.

SUMMARY

In this discussion, I have attempted to show the merits of water reclamation as a concept. It may be that in some areas of the world, wastewater reuse, aside from its merits, will soon become an absolute necessity, as it already is in Africa.

We have seen what our nation's scientific and technological forces have been able to accomplish in both the nuclear and outer space areas when given unlimited financial support. If our national government supports their verbal pledges with actual appropriation of funds, we can expect that a large part of the nation's technical resources will move into the environmental control fields. Probably, in our usual manner, we will waste a lot of money and effort in our rush to develop solutions. However, there can be no doubt that the end result will be the development of many valuable new processes not known today.

The decade of the 1970's may well mark the era when America realizes that only "wastewater" fit to drink is fit to throw away. If that criterion should indeed be adopted by our society, I am certain that the technology will exist to accomplish that goal at a cost which we will be able to bear.

Finally, I would leave you with this thought: If the only water fit to throw away is fit to drink, then there is obviously no such thing as "wastewater." I believe we should discard this word from our vocabulary and along with it such terms as sewage and refuse liquids. We should come to realize that there is no such thing as new water; nearly all water or the earth's surface has been used and reused in one way or another. Perhaps we should refer to the water which carries our wastes as "transport water." Then in our treatment plants we can remove the pollutants from the water used to transport the pollutants to the plant and end up with plain water. The result might be far more acceptable to the public than trying to get them to drink "reclaimed sewage."